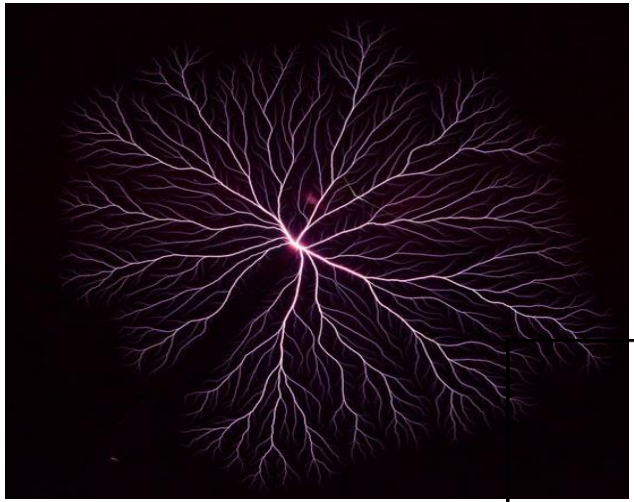
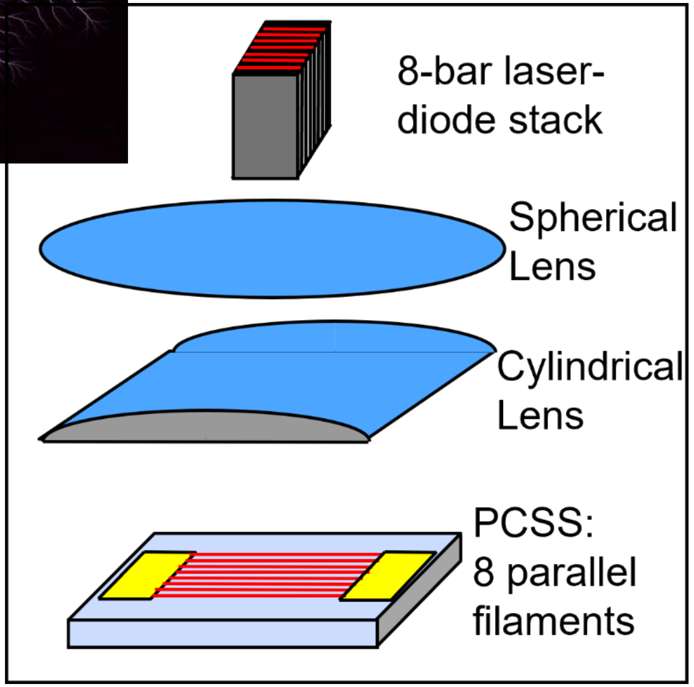
UNM SCHOOL OF ENGINEERING

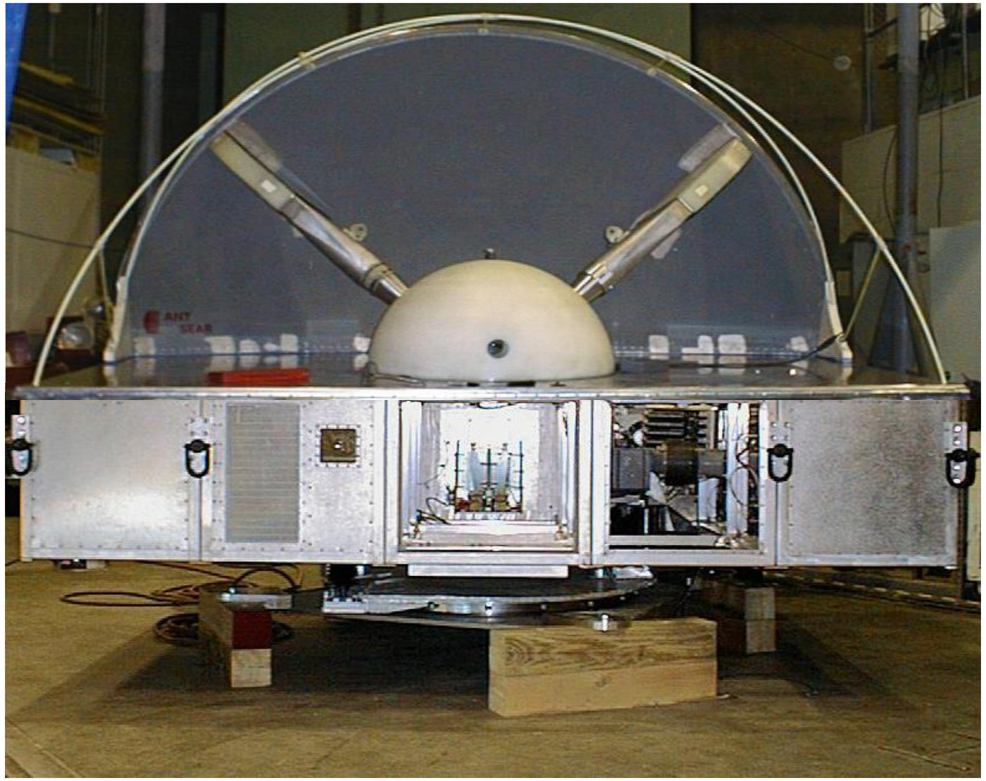





# Systems Aspects for Ultrafast Switching

Prof. Jane Lehr
University of New Mexico

# Portable Ultra-Wideband Radiating Sources



Impulse Radiating System met both Peak Field & PRF specifications!

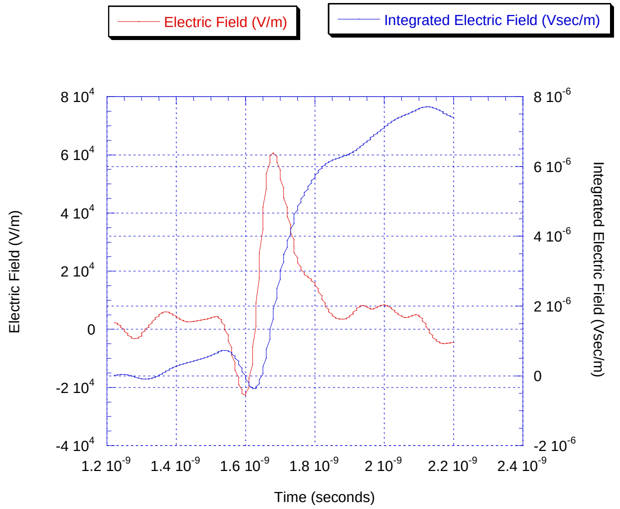
Vp =1.2 MV
Tr = 200 ps

World record for
Peak **E** at distance

**First ACTD at Kirtland AFB**

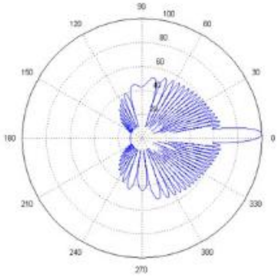
**Two Important Lessons:**

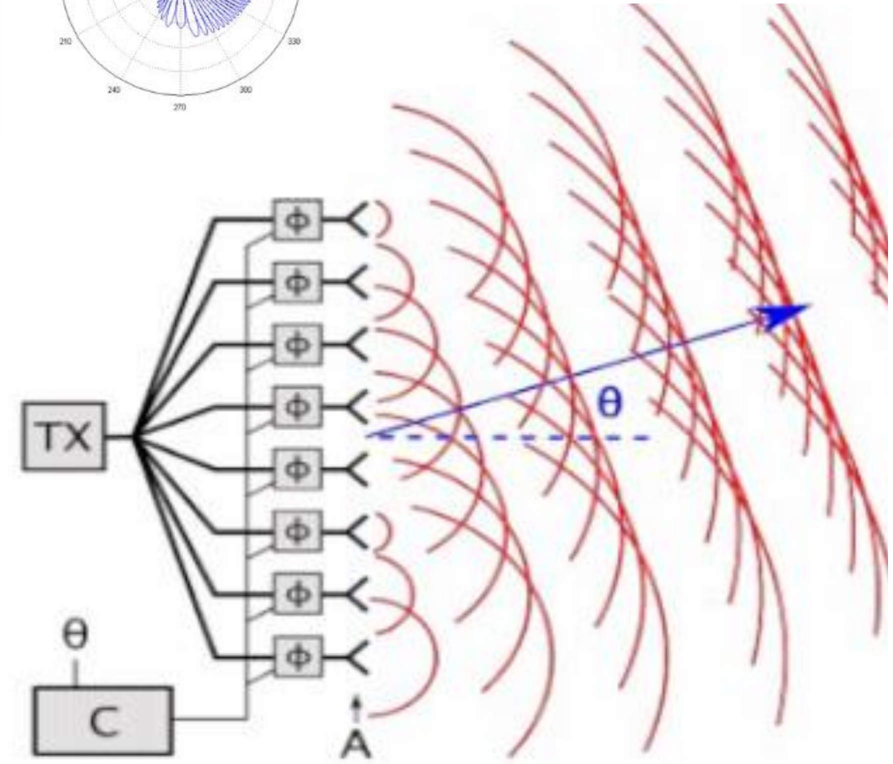
- **Systems Perspective**
- **Identify Physics Limits**

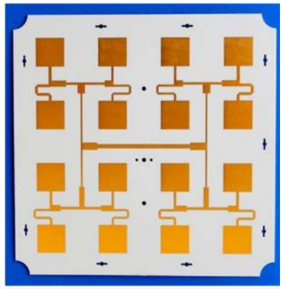


# Antenna Arrays

## Directive pattern



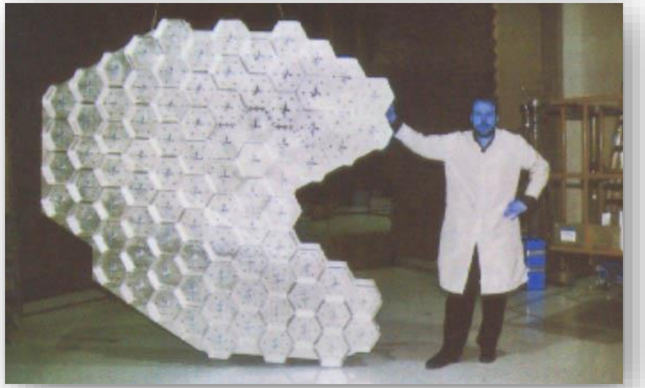




Microstrip Array

## Electronic Beam Steering

No moving parts
Low profile
Can be conformal
Facilitates multibeam
Self pointing



## Adaptive Directivity

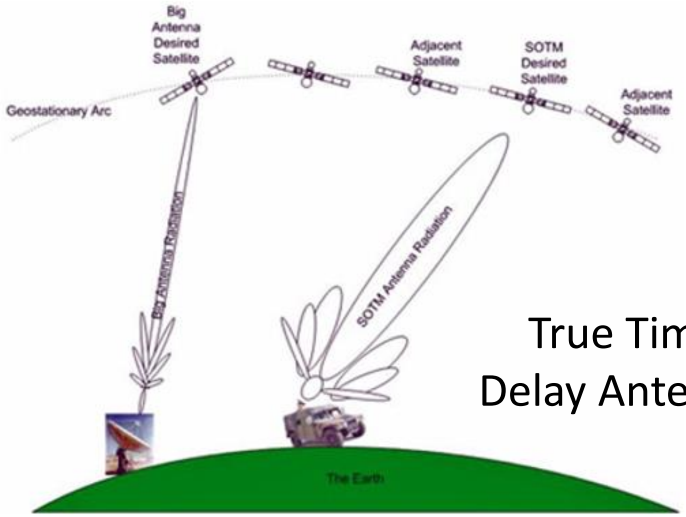



Figure 1. Adjacent Satellite Interference Constraints

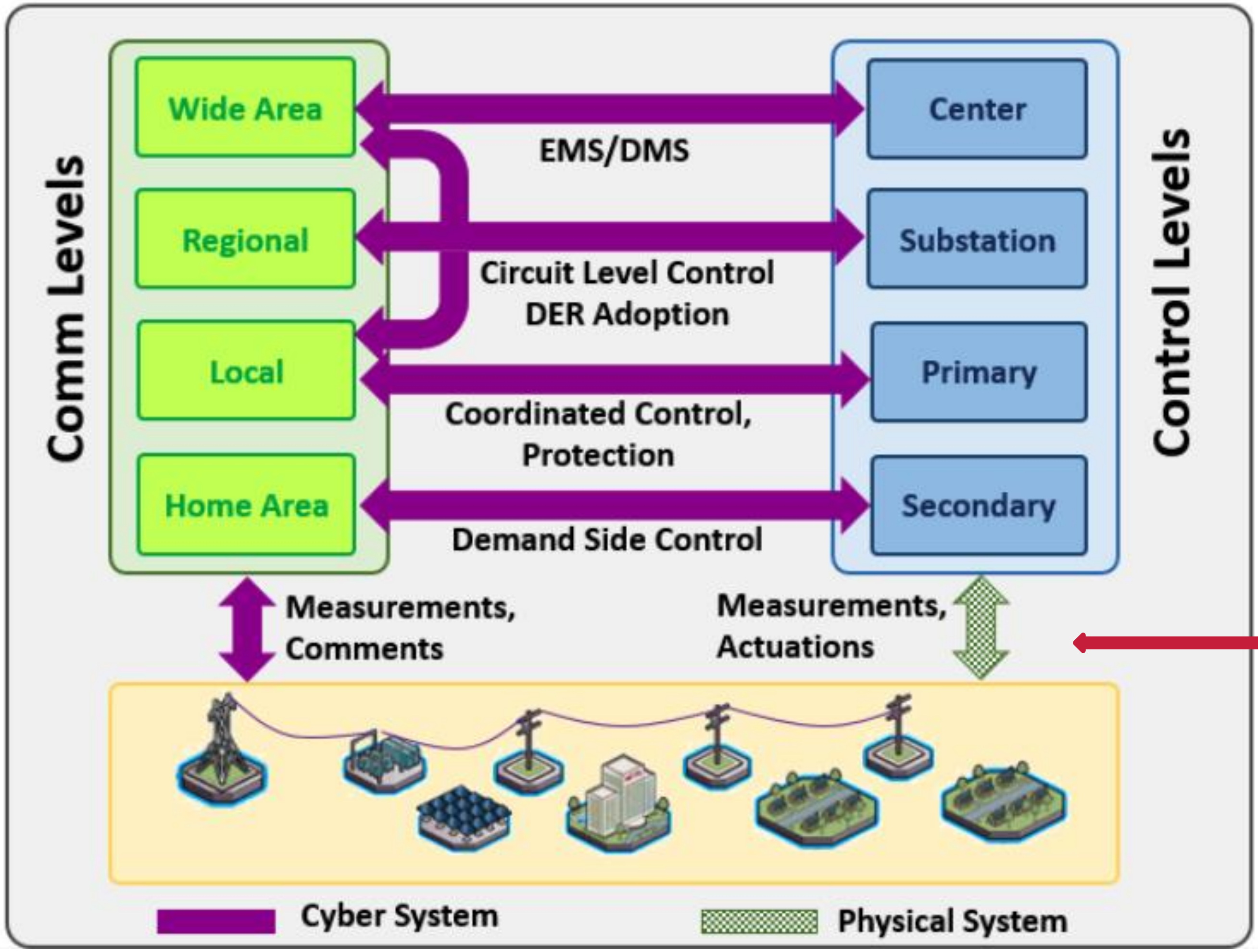
True Time Delay Antennas

$$\Delta t \leq 0.1\frac{T}{4} = 0.1\frac{\lambda}{4c}$$

**Ultrafast Switching Enables**

**Modularity, Protection & Control**

# Cyber Physical Control System for Grid



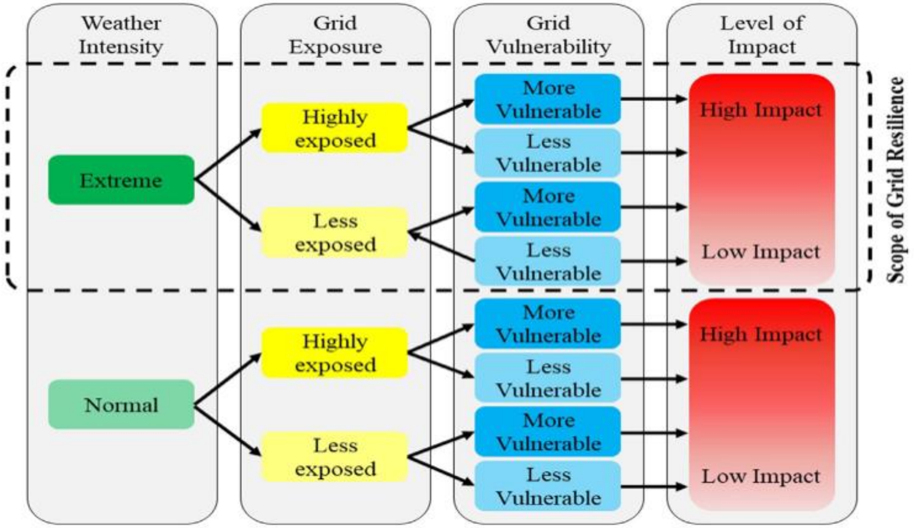

R. Arghandeh, et al, "On the definition of cyber-physical resilience in power systems." *Renewable and Sustainable Energy Reviews* 58 (2016): 1060-1069.

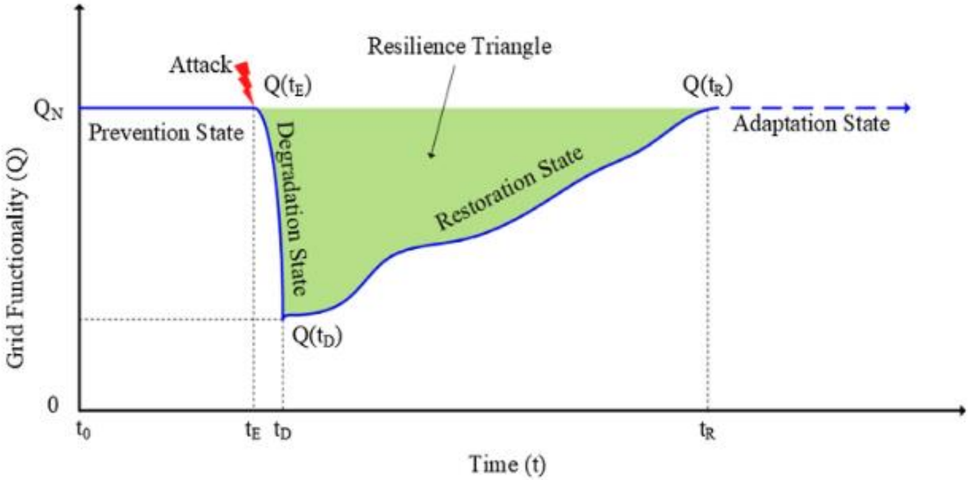
Robust-Recoverable

Power transmission and distribution networks are greatly dispersed and highly **complex** engineering systems with different degrees of connectivity. One of the key issues is that the **dynamic** electricity supply and demand balance needs to be maintained in **real--time**. Natural disasters, severe weather and attacks make reliable operation a very difficult task.

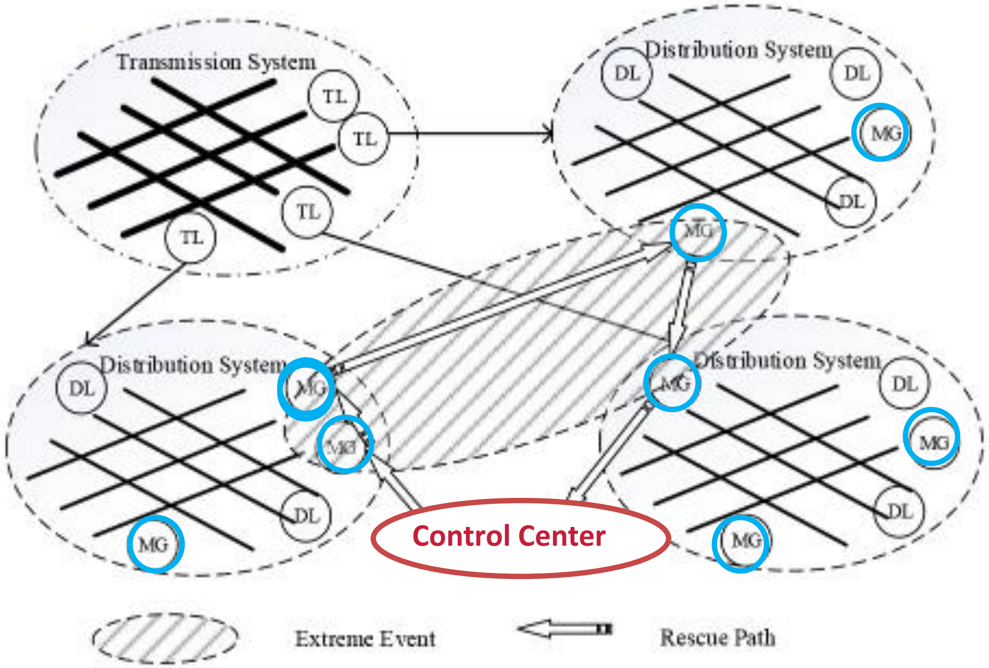
**Ultrafast Switches**

# Resilience Framework



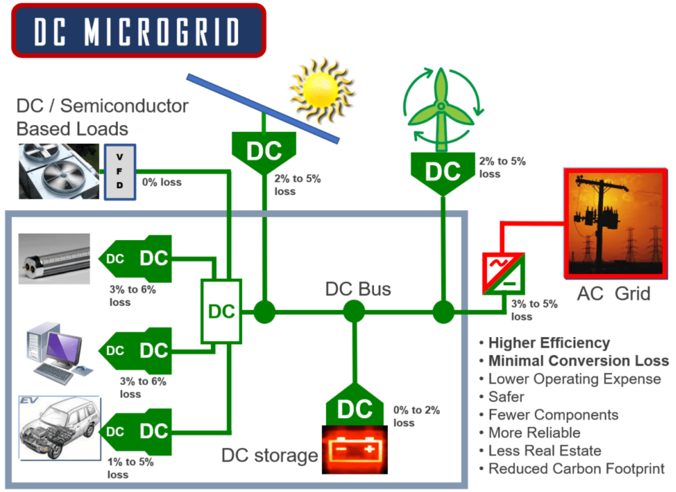

Grid Recovery Strategy Including microgrids




Jufri, Fauzan Hanif, Victor Widiputra, and Jaesung Jung. "State-of-the-art review on power grid resilience to extreme weather events: Definitions, frameworks, quantitative assessment methodologies, and enhancement strategies." *Applied energy* 239 (2019): 1049-1065.; X. Liu, et al "Microgrids for Enhancing the Power Grid Resilience in Extreme Conditions," in IEEE Transactions on Smart Grid, vol. 8, no. 2, pp. 589-597, March 2017, doi: 10.1109/TSG.2016.2579999.

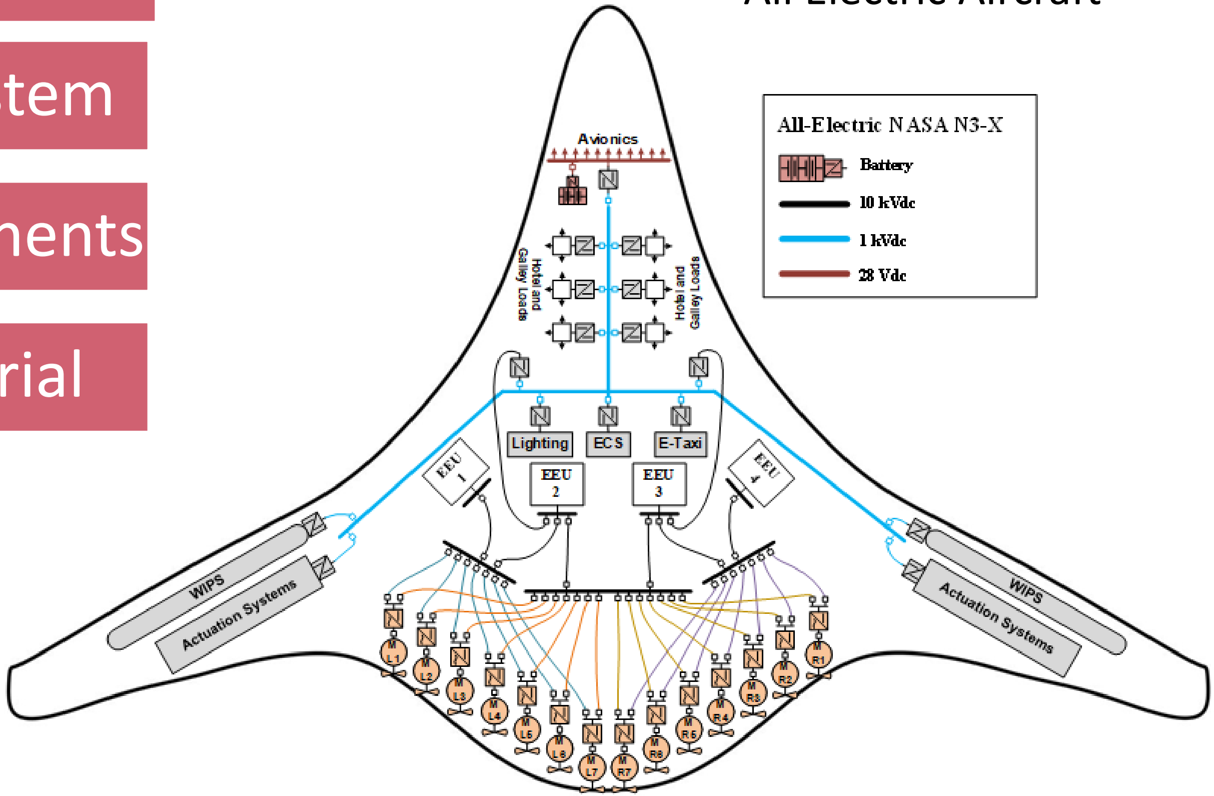
# Speed of control/ Size of Circuit

Next Generation DC System: Energy loss is reduced at multiple points of operation




Resilience
- Application
- Subsystem
- Components
- Material

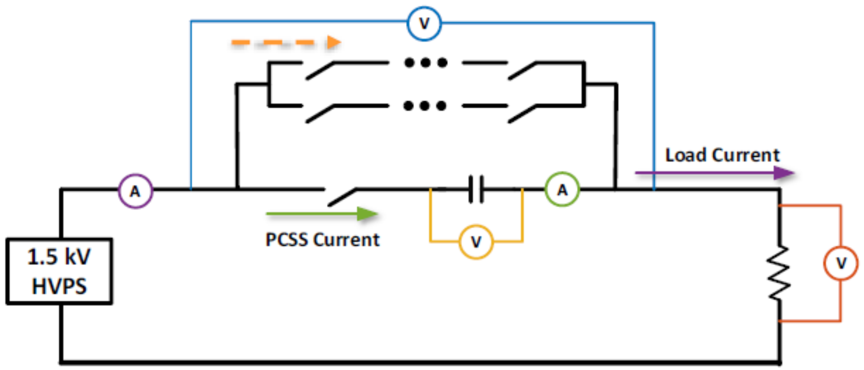
All Electric Aircraft

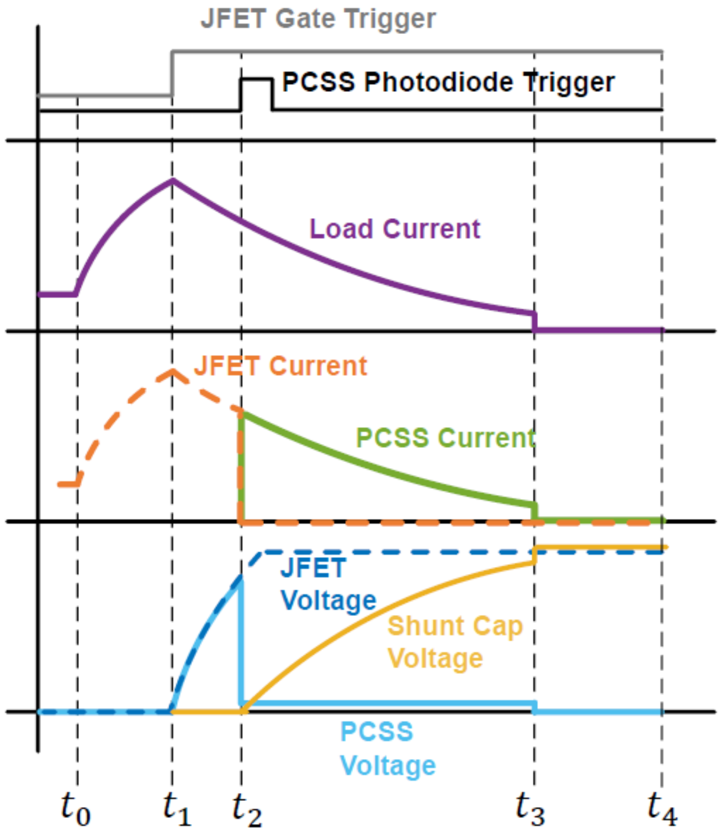



**Small Circuits need Faster Detection and Response for Protection and Resilience**

# DC Circuit Breaker Demo Behavior was Predicted

- Test sequence includes the opening and closing of relays for safety purposes
- Based on protocol and circuit theory, circuit behavior (i.e. waveforms) can be predicted
- Time intervals are sensitive to current levels




Interval I $[t_1 - t_0]$

- Fault current rises at $t_0$ until $t_1$ when the fault current is detected, turning JFETs OFF

Interval II $[t_2 - t_1]$

- JFET voltage starts to rise at $t_1$ and JFET/load current starts to decrease.

Interval III $[t_3 - t_2]$

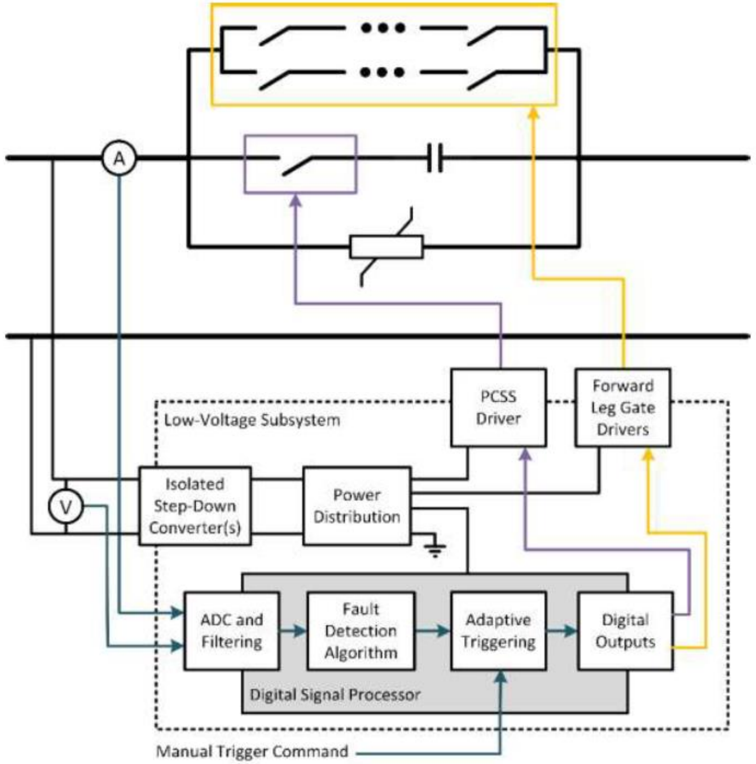
- PCSS is triggered at high-gain mode at $t_2$, diverting fault current from JFET leg to shunt cap.
- Shunt capacitor voltage rises based on RC value.

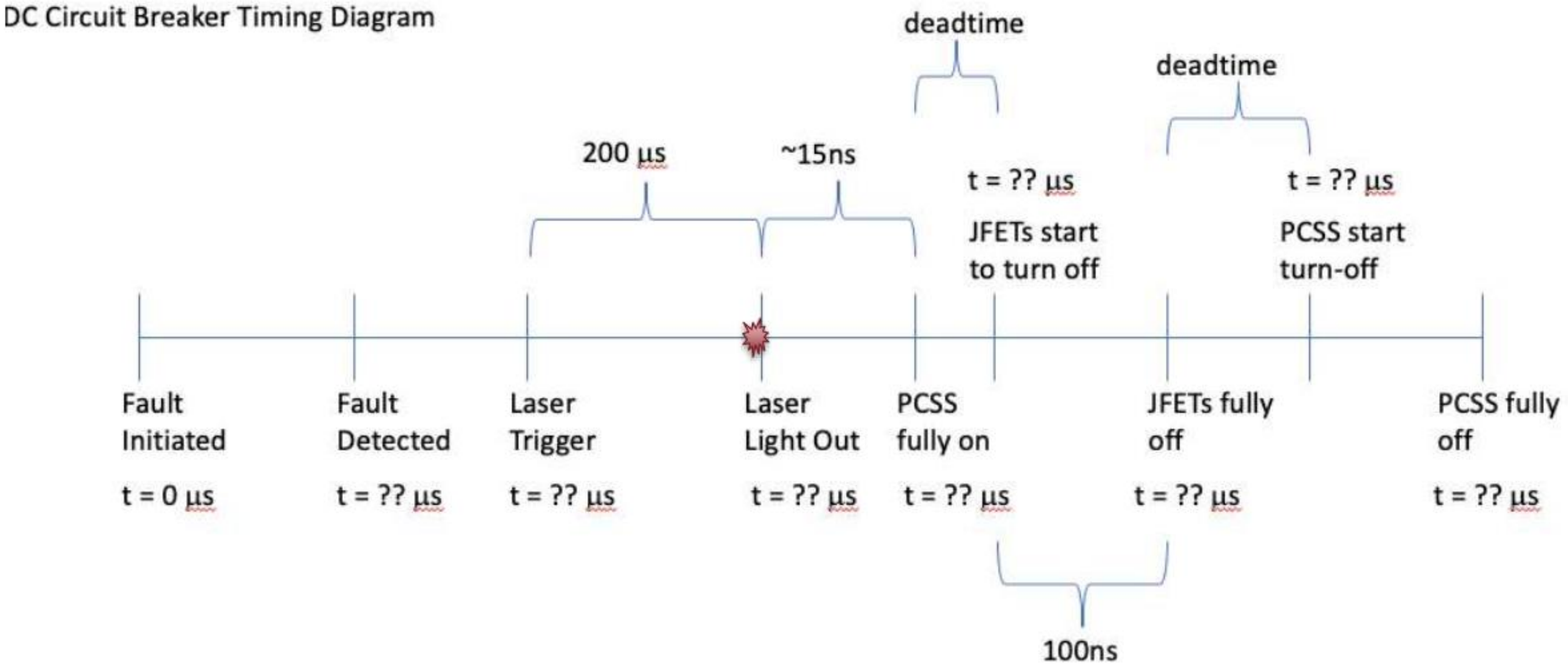
Interval IIV $[t_4 - t_3]$

- PCSS voltage reaches OFF state and breaks remaining current.

# DC Circuit Breaker Timing Diagram

**A lot of tasks must occur  have to occur in that 500 µs!**




Time budget for fault detection-to- switch actuation ~ 500 us

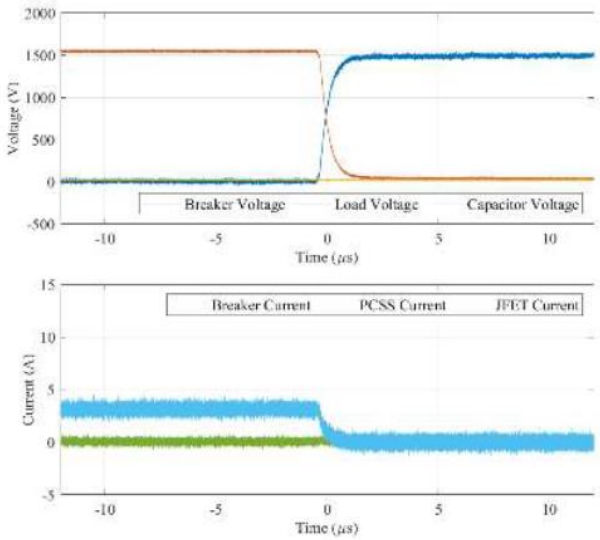
- The normally on leg will turn off in about ~100ns.
- ~ 10's of ns for deadtime on either side

# Laser Parameters: Wavelength, Peak Power, Pulse Length, Jitter …. And delay time

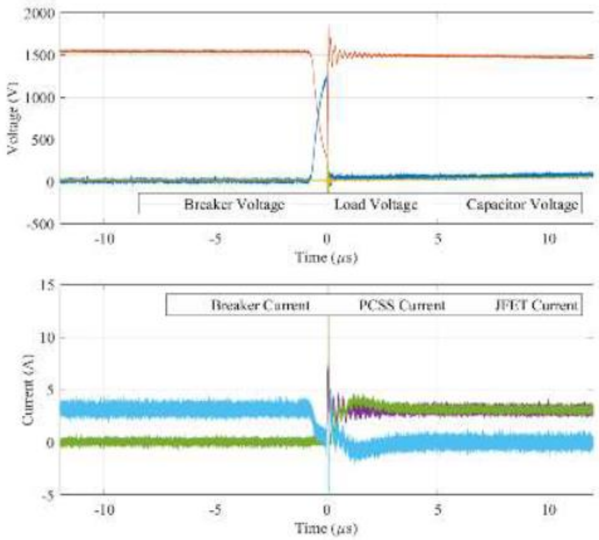
**Not typically provided by manufacturer**

## Testing determined Circuit behavior is sensitive to laser jitter

- Laser trigger at t=0, but laser jitter causes it to fire at various voltages in the ramp during JFET turn off




**PCSS didn't trigger into lock on mode**
**~905 V on PCSS when laser trigger occurred**

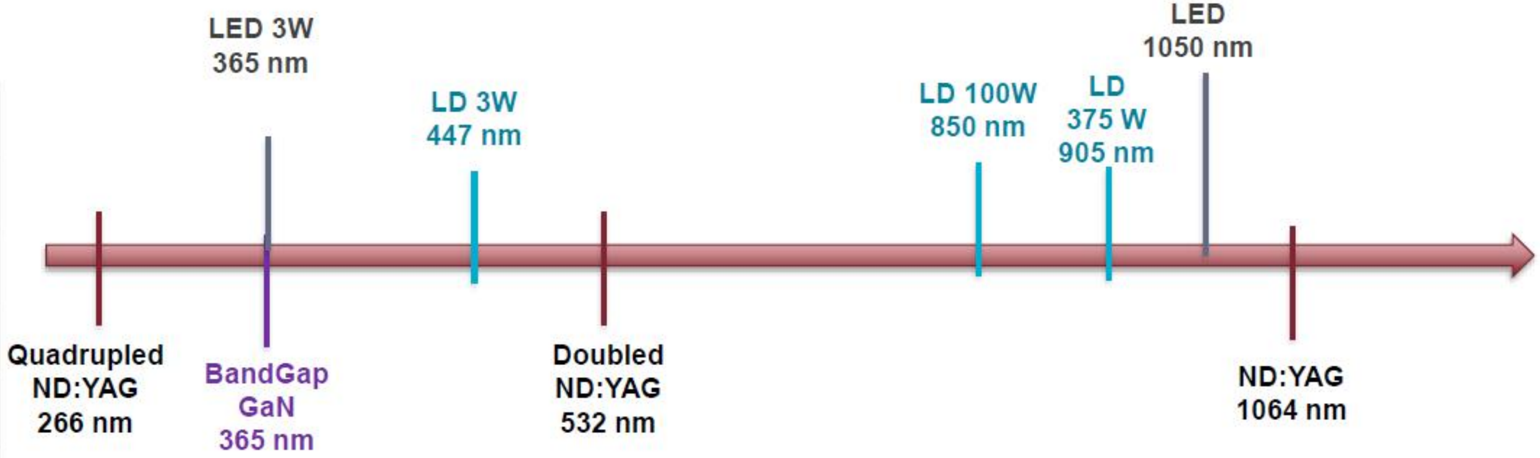



**PCSS triggered into lock on mode**
**~1230 V on PCSS when laser trigger occurred**

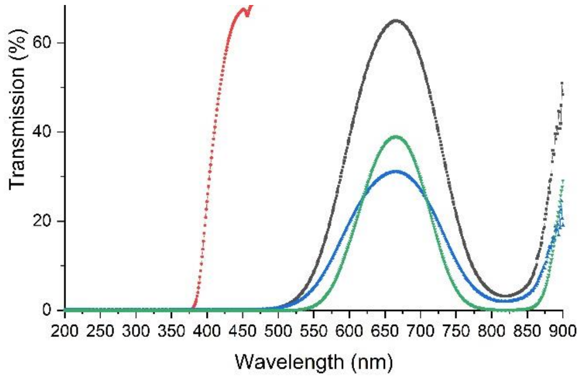
# Laser and Laser Diode Wavelength Options

| Laser Type | Wavelength |
|---|---|
| Argon fluoride (UV) | 193 |
| Krypton fluoride (UV) | 248 |
| Xenon fluoride (UV) | 308 |
| Nitrogen (UV) | 337 |
| Argon (blue) | 488 |
| Argon (green) | 514 |
| Helium neon (green) | 543 |
| Helium neon (red) | 633 |
| Nd:Yag* (near IR) | 1064 |
| Carbon Dioxide (far IR) | 10600 |

* Neodymium-doped yttrium aluminum garnet




This may be a physics limit

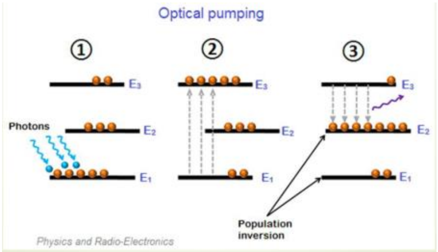


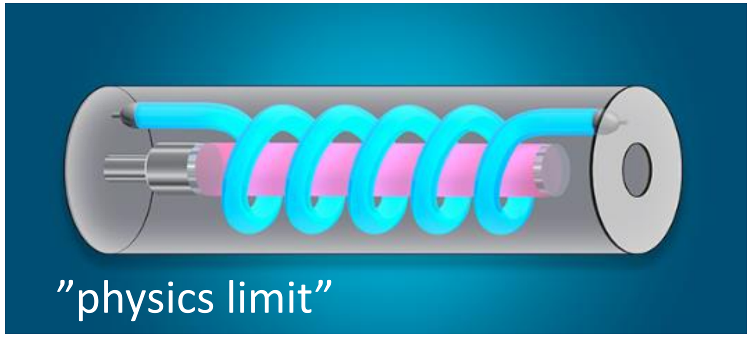

<u>Optical Energy</u>

- 10µJ to 1mJ of 532nm with 5 ns pulse width light required in previous experiments
- Laser diode and LED sources available in powers from mW to 100+W for CW operation
- Conversion from optical power to energy is time dependent.

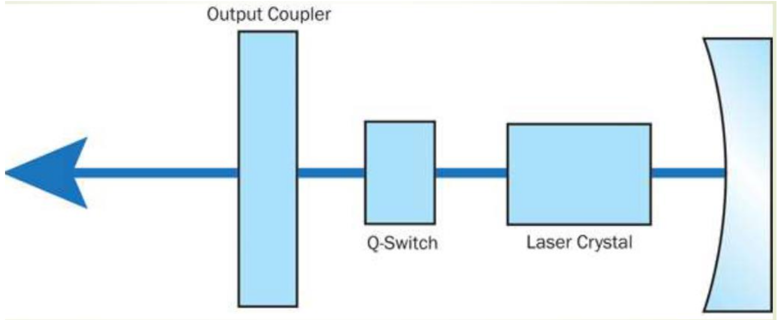
# Through-time for DC breaker includes laser

Atoms remain
In the upper level
for a long time



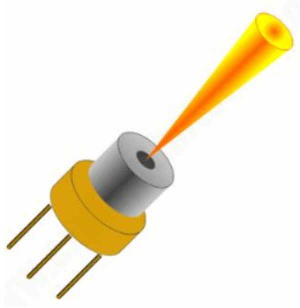



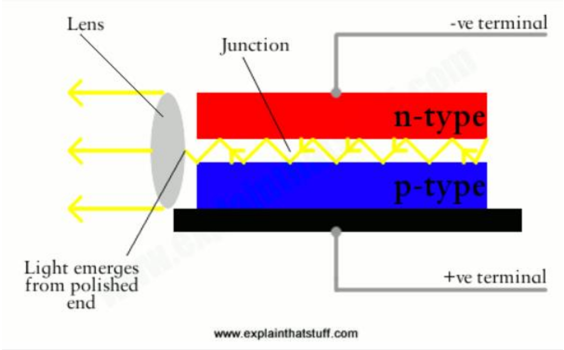

Time to fill cavity is large part of delay



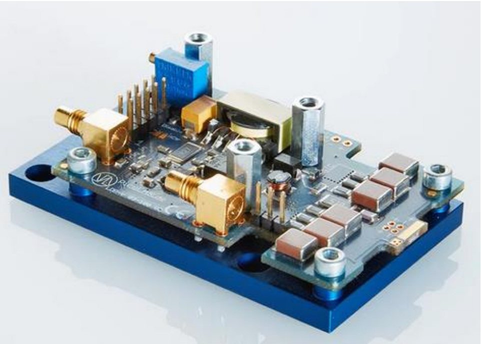

Passive Q switched can have ~ 200 μs delay
and 10 μs jitter

Simple Laser Diode
Is current pumped
& releases light quickly






650W LD has 10 ns
turn on time

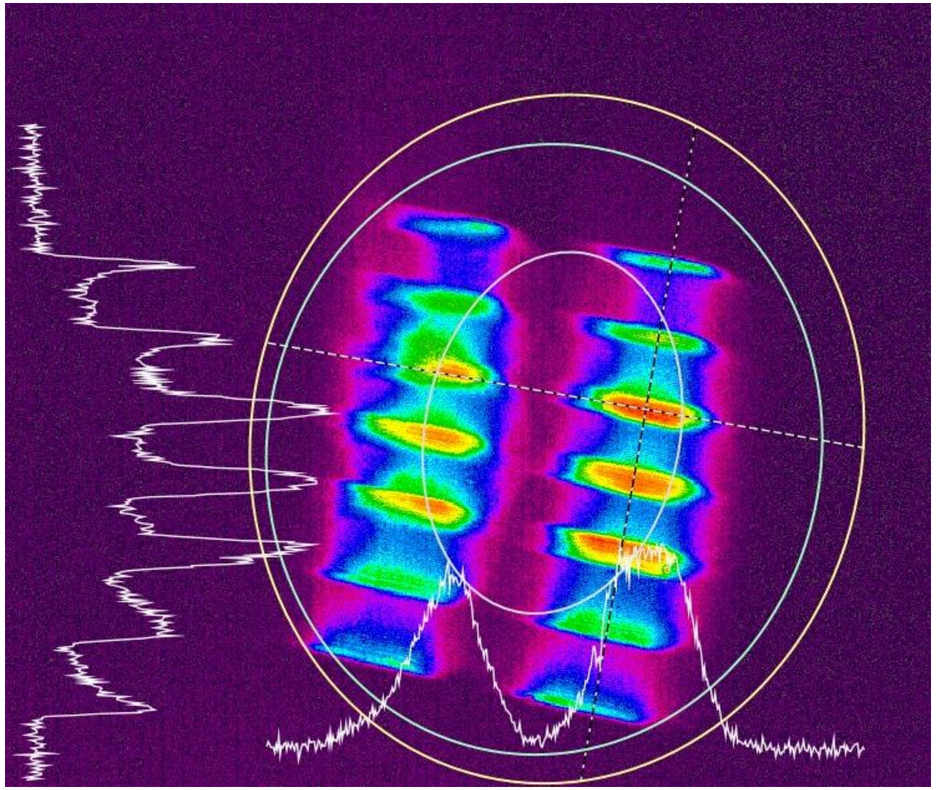


Driver 150 ps jitter
(measured)

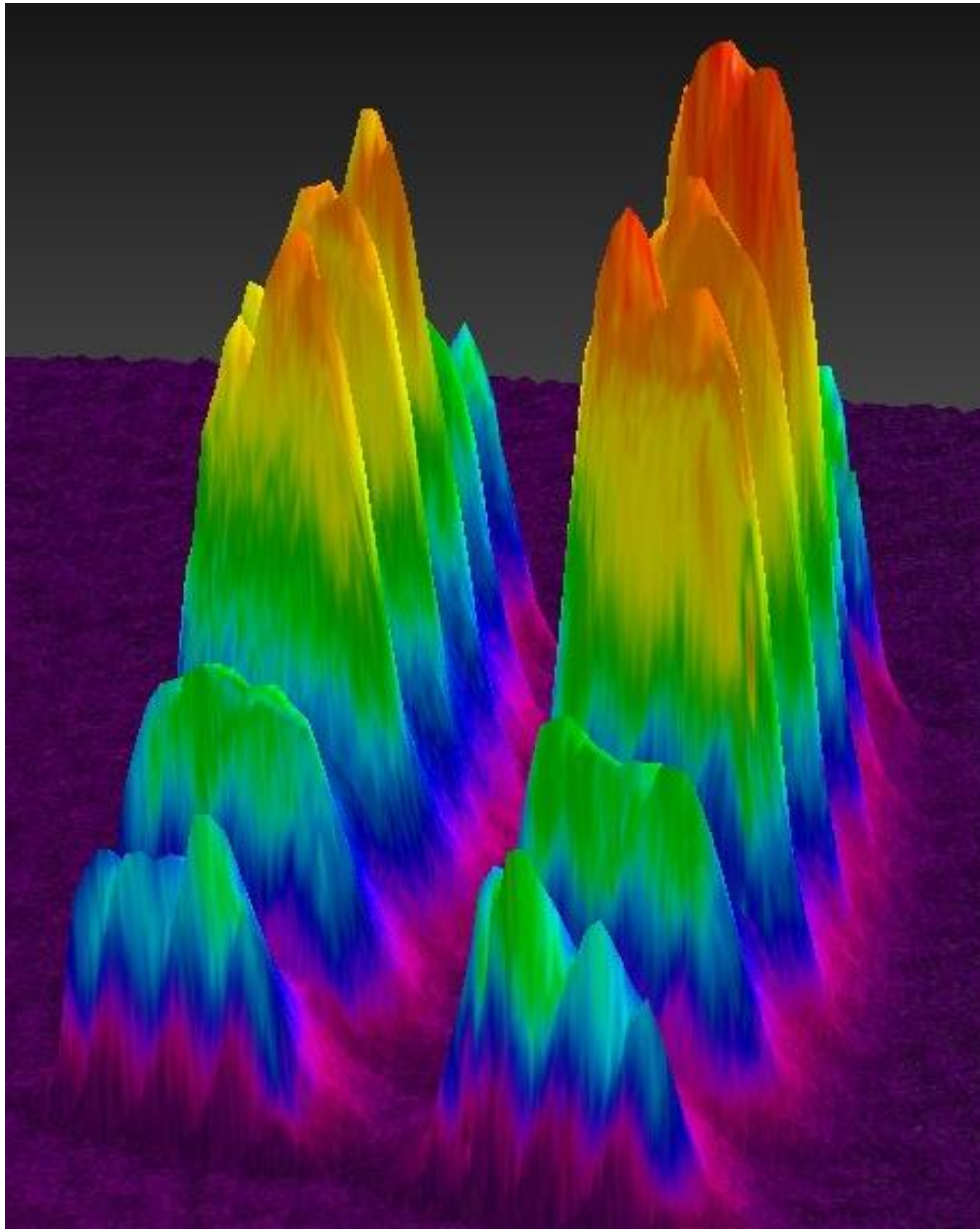
**Laser technology is very market driven**

# Laser Beam Profile after collimation

650W@905 nm



The measured beam profiles shows our laser diode is a “wide stripe Laser diode” which radiates multiple quasi-gaussian TEM modes. This makes the collimating and focusing of our laser challenging.

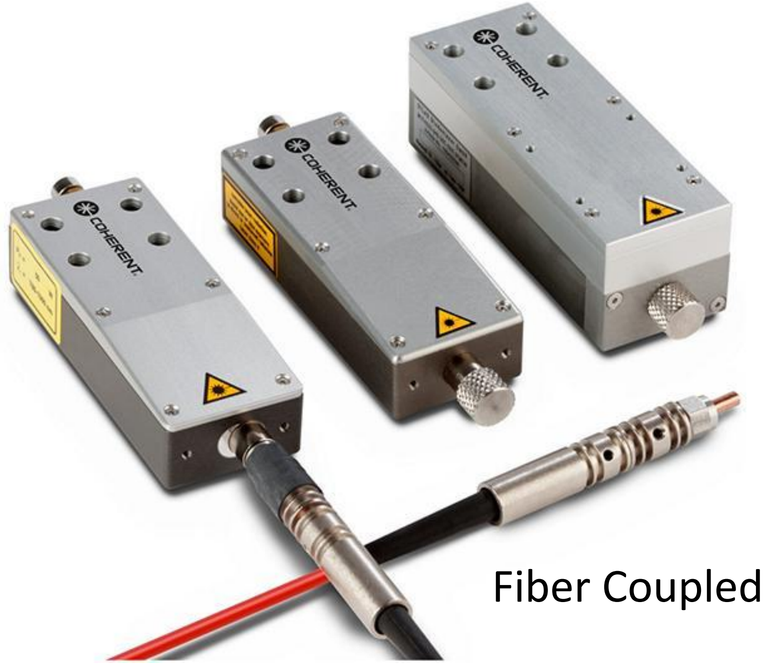


# Light triggers

Fiber delivery

- EMI resistant
- Multiple triggering
- Allows remote actuation

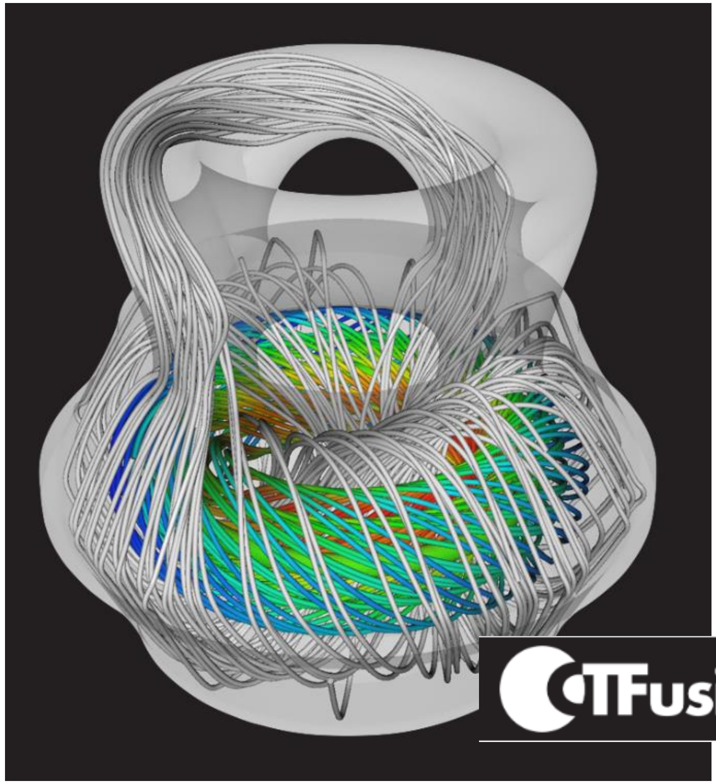
Fiber Coupled Laser Dioc




Fiber Coupled Laser


**Laser technology is very market driven**

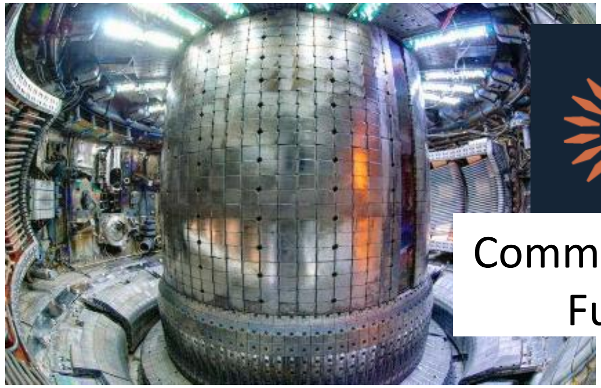
# Fusion: Limitless Clean Energy




The **elimination of electrodes**, high power **efficiency** and **dynamic** plasma stabilization provides a favorable scaling … & can operate continuously with **multiple** helicity injectors phased appropriately in time.

One glass of water will provide enough fusion fuel for one person's lifetime.

Commonwealth Fusion website



Commonwealth Fusion

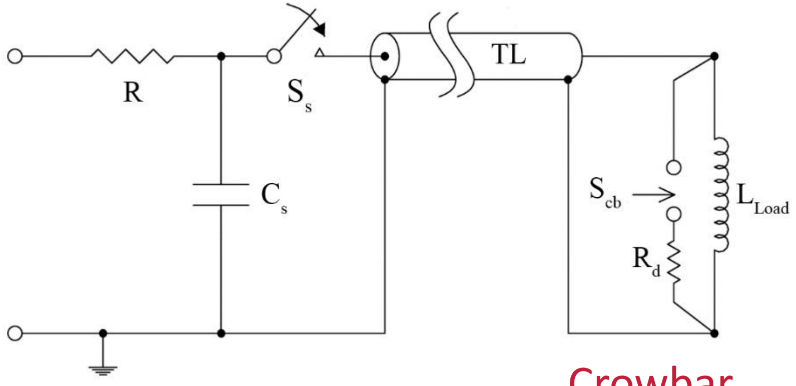
**Fusion Requires Highly Reliable Current Drivers**

Zap Energy is building a seriously cheap, compact, scalable fusion reactor without costly and complex magnetic coils.

# LANL's Plasma Liner Experiment (PLX)

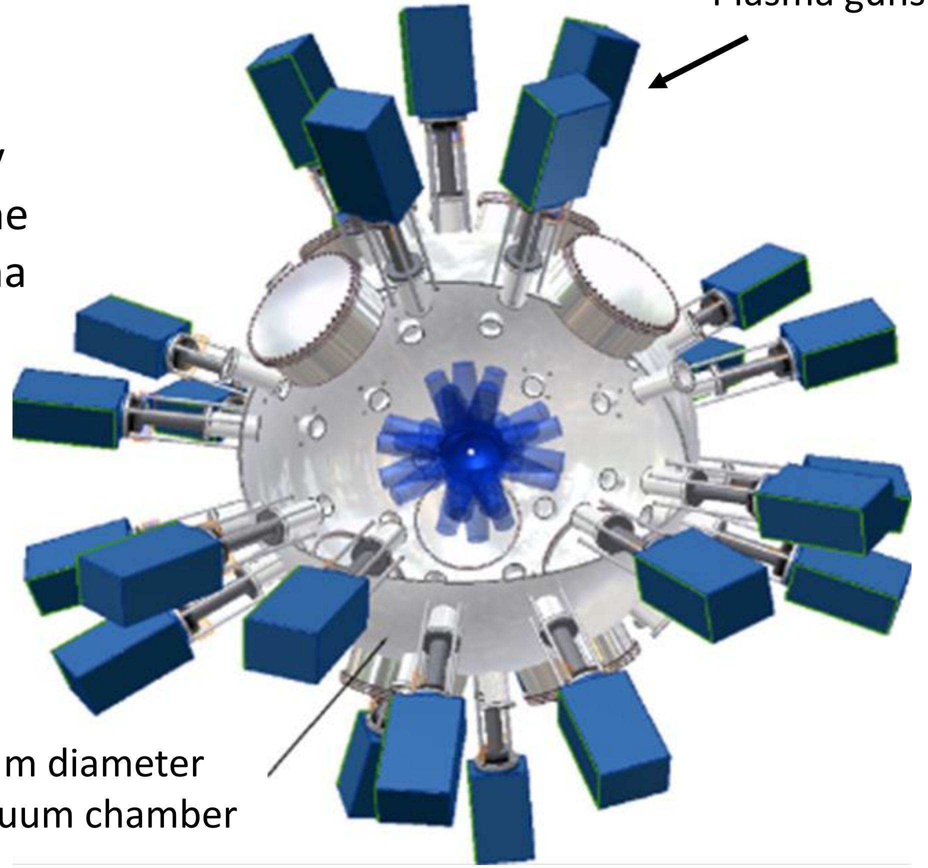
**Reliability implies Repeatability**

**Modularity requires Simultaneity and Fast Triggered Protection**



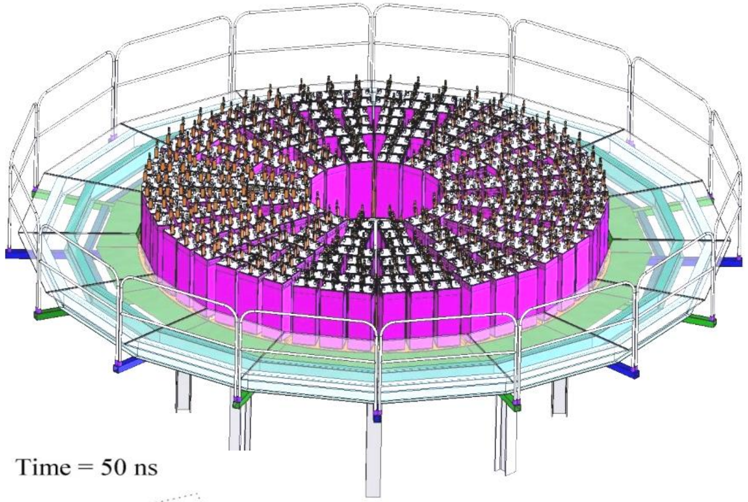

Crowbar

PLX shows the plasma gun array Needed to heat the magnetized plasma

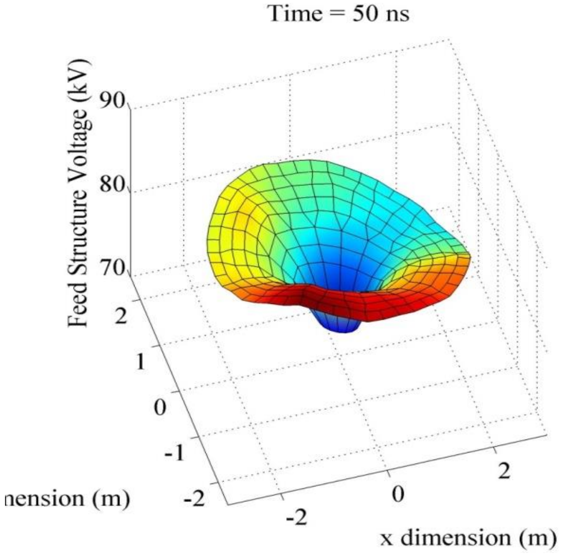


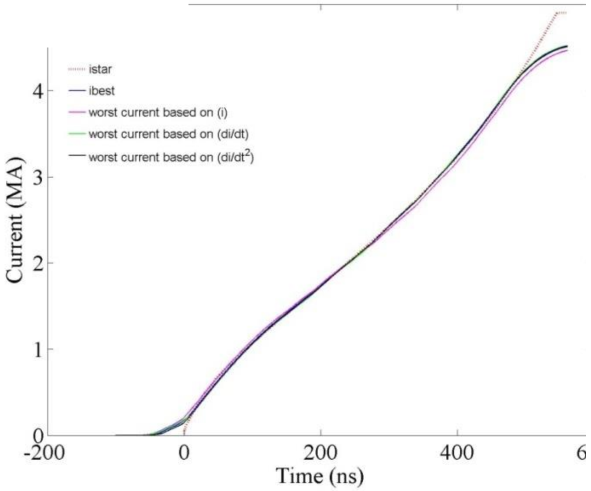

PLX's goal is to demonstrate the compression & heating of a magnetized D-D plasma to fusion conditions by a spherical plasma linear formed by an array of hypervelocity plasma jets

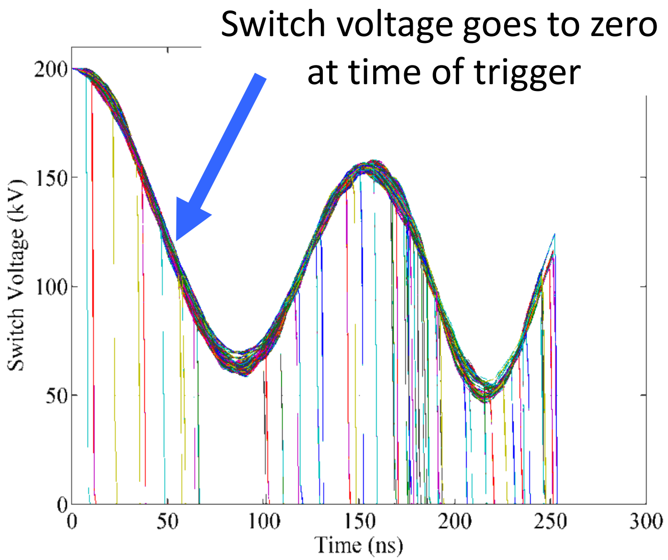
# Genesis: Isotropic Compression Experiments



- Switches are contained in **240** tightly coupled modules & 60 trigger points.
- Transmission line voltage varies in time and location, resulting in varying voltages across untriggered switches.

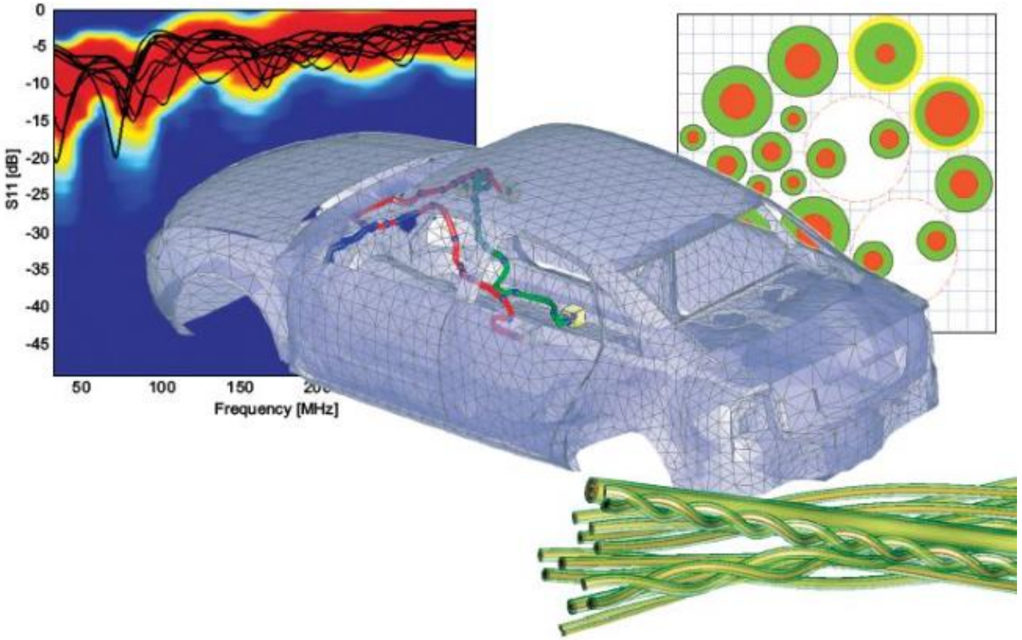


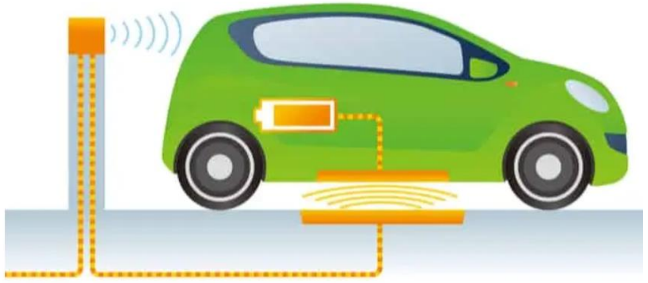




**Switches need a broad operating capabilities**

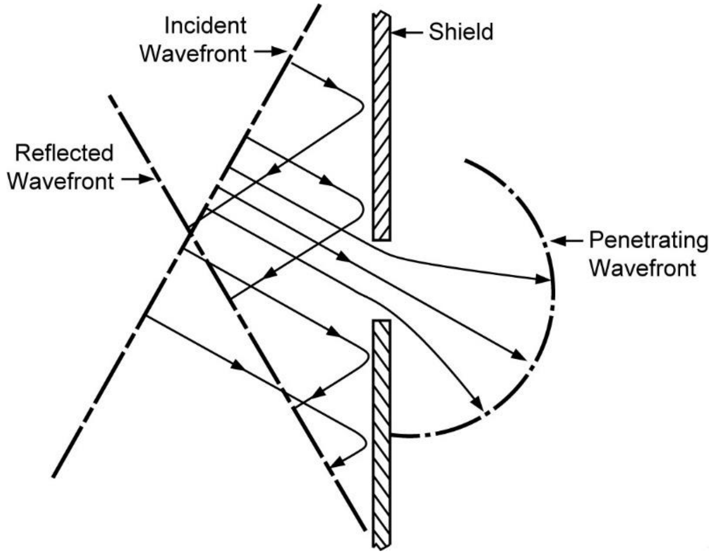
# Increasingly Complex Electromagnetic Environments



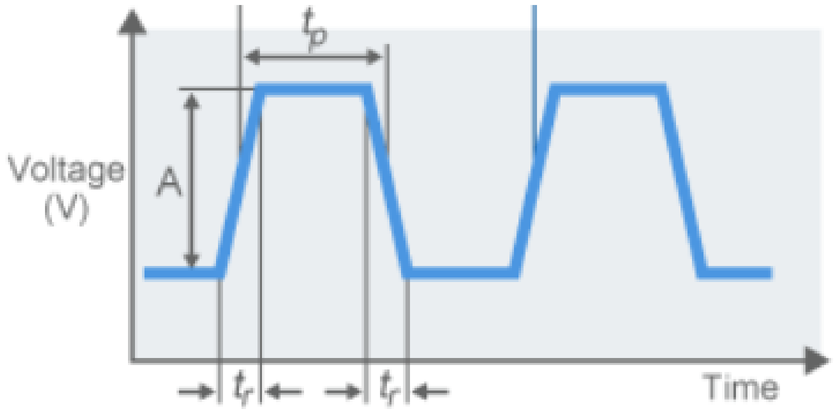



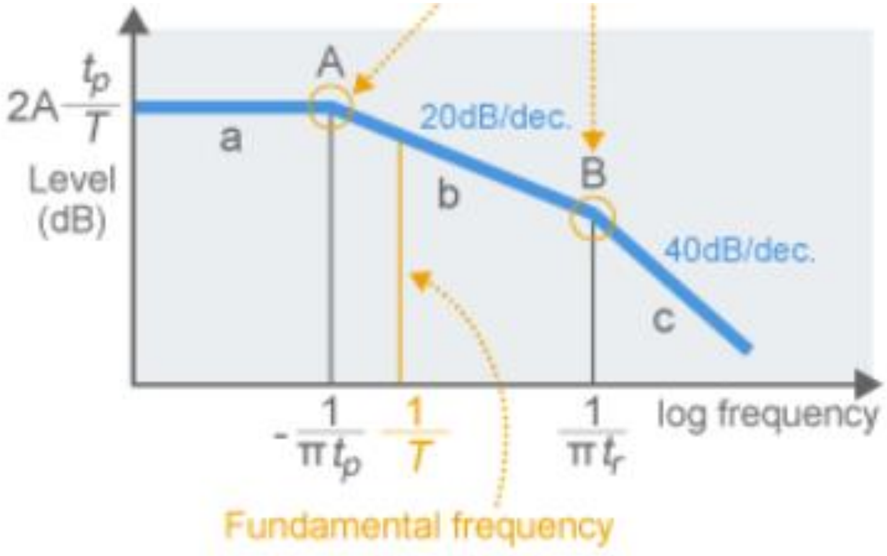
Multi timescale Radiators + Various Coupling

Coupling depends on wavelength



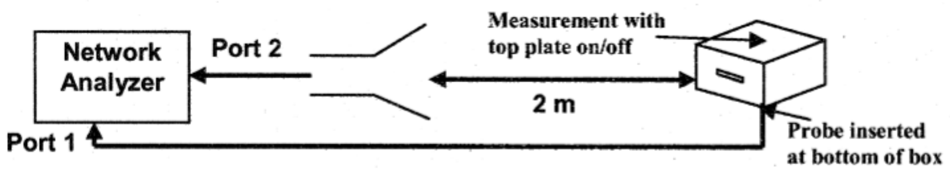
# Time – Frequency



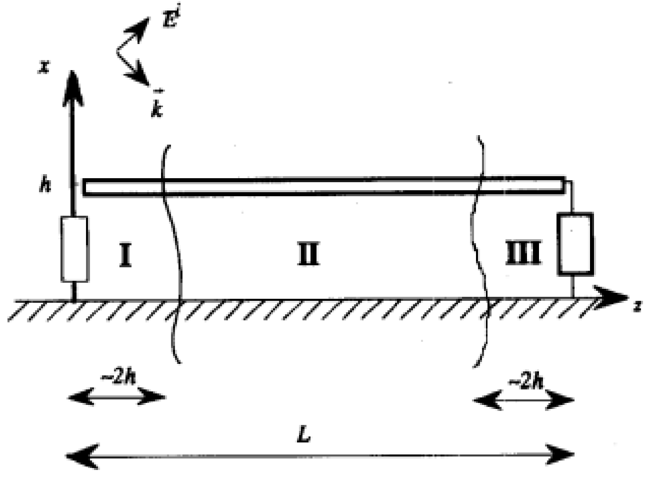




**Radiated Emissions**

**Apertures**




Fast risetime ⟷ High frequency/short wavelength




Transmission Lines couple to frequencies corresponding to their length

# Frequency - Length and the Microwave Condition

$$0.1\lambda < d_{ckt} < 10\lambda$$

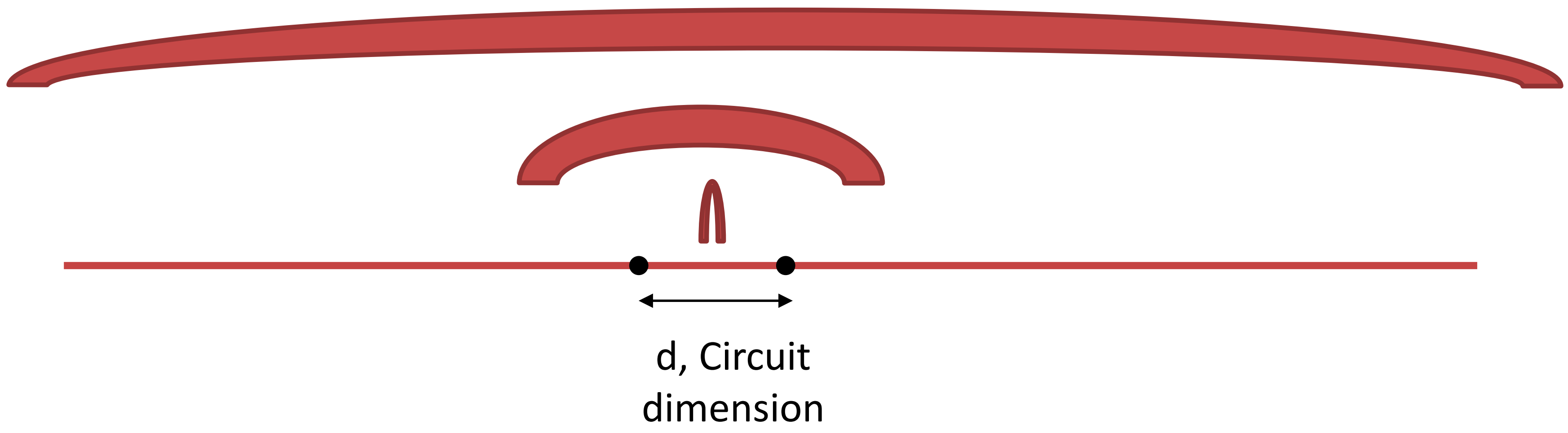
$d_{ckt}$ = circuit dimension

$\lambda$ = excitation wavelength

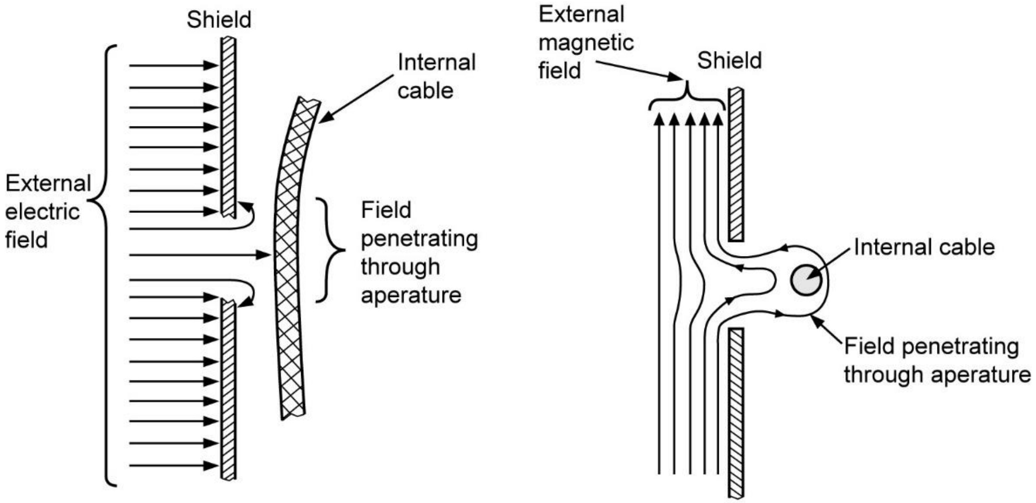
Lumped Circuit d << λ

Microwave d ~ λ

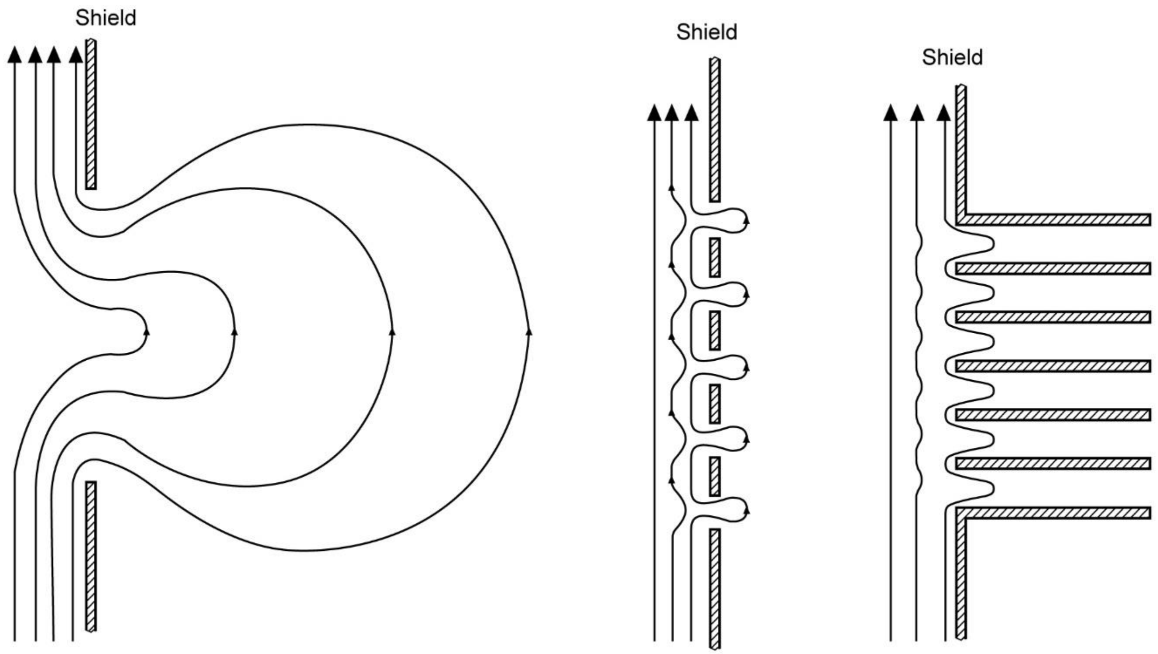
Optic d >> λ



# Apertures



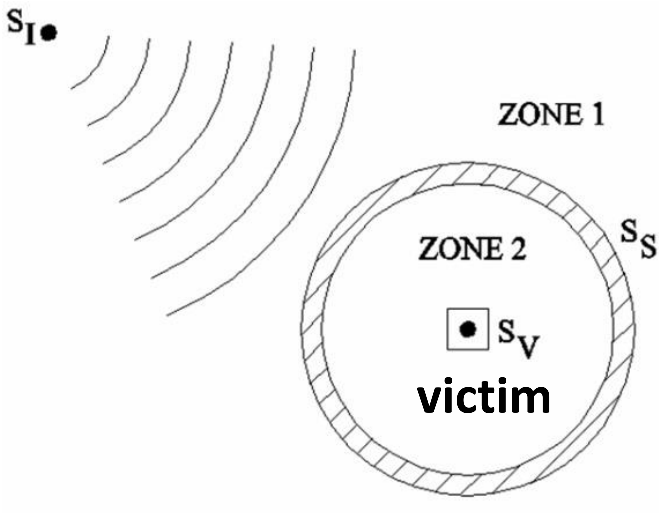

(a) Electric Field (b) Magnetic Field



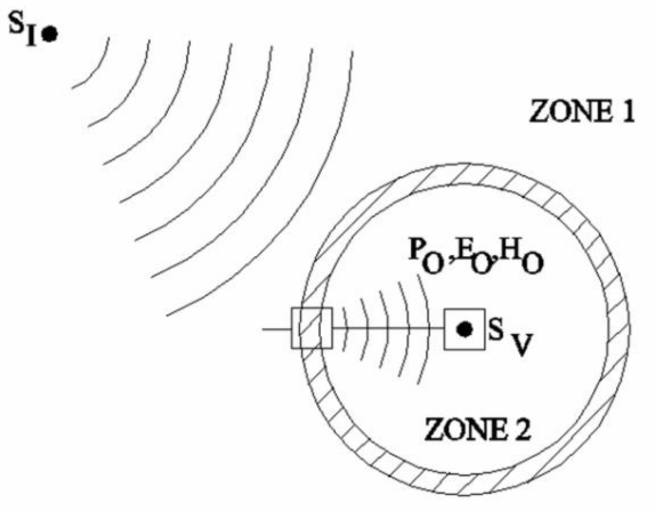

(a) Single Aperture (b) Many Small Apertures (c) Array of Waveguides Beyond Cutoff

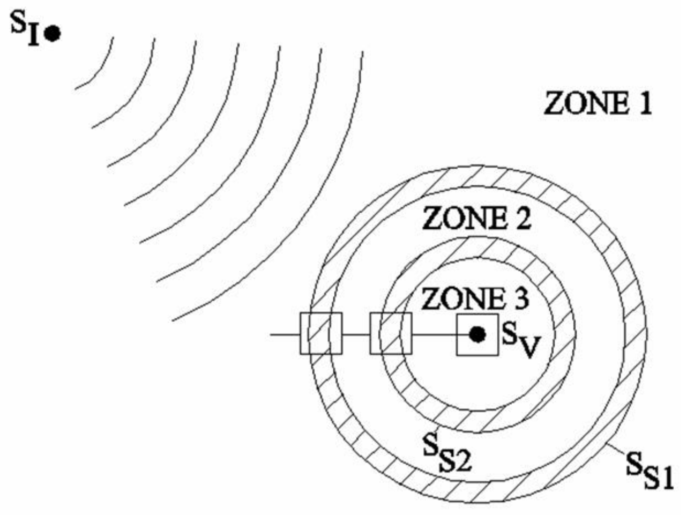
# EM Topology – Heirarchical Approach to EMC

source

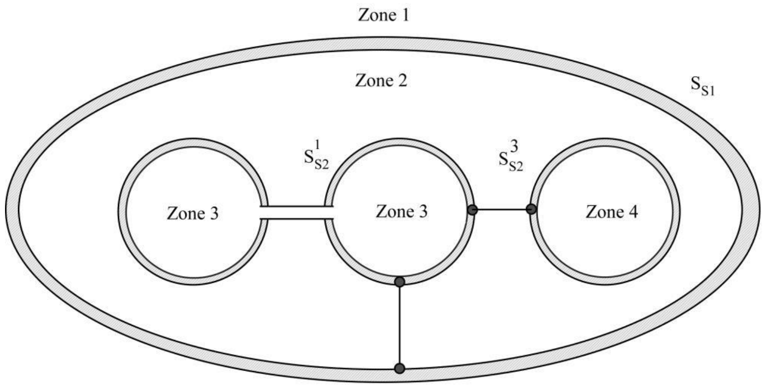


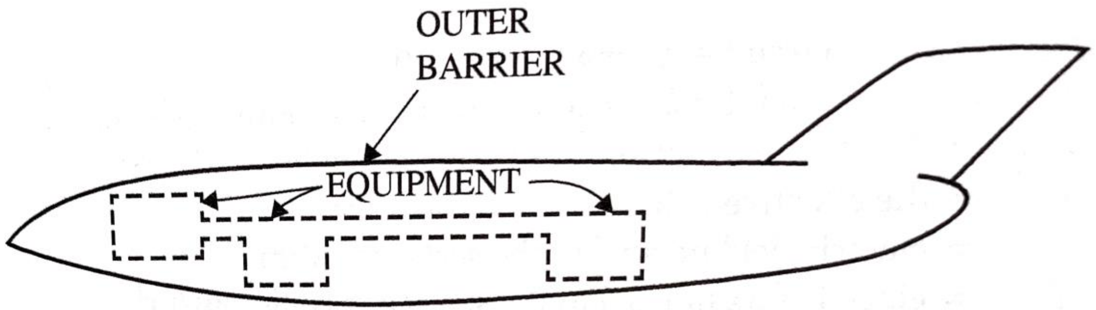

Allows for shielding techniques though out the spectrum

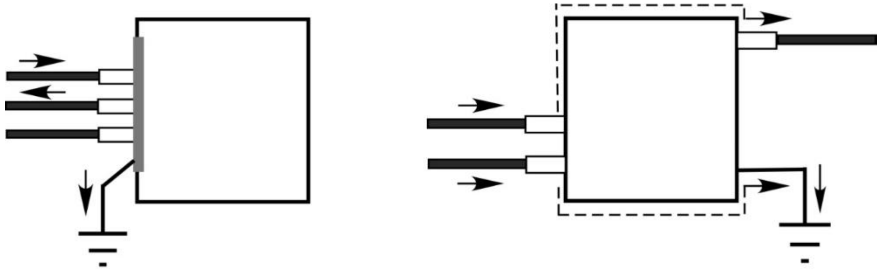


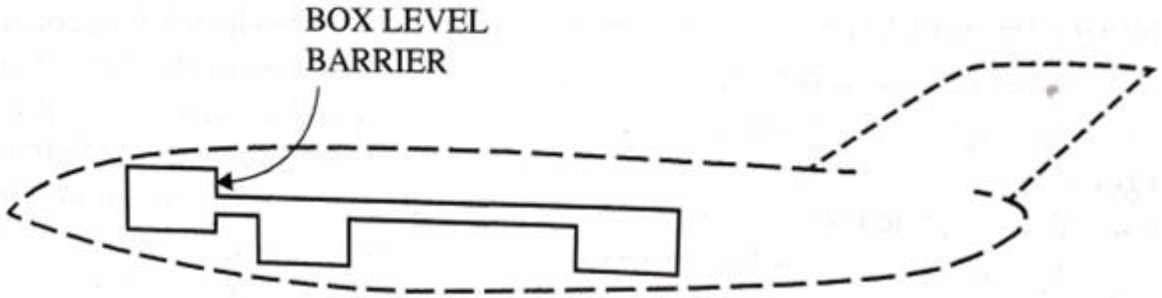



# Shielding Topology

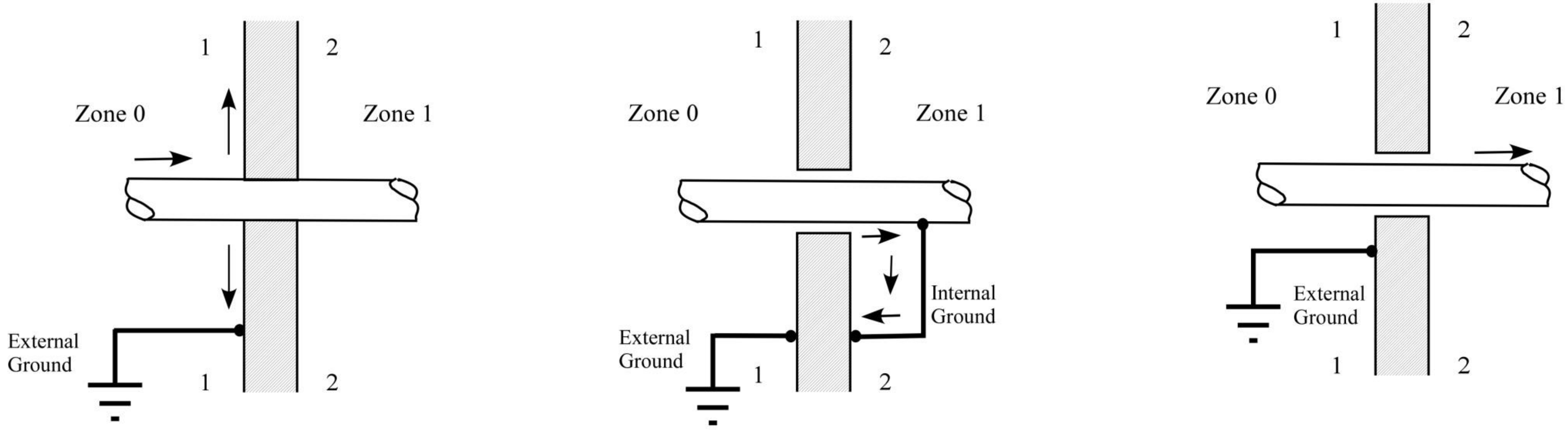




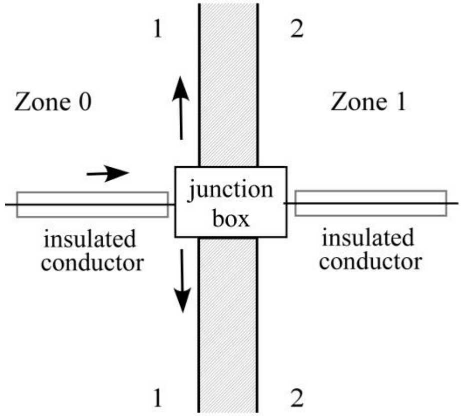
# Penetrations & Conducted Emissions




(a) Good

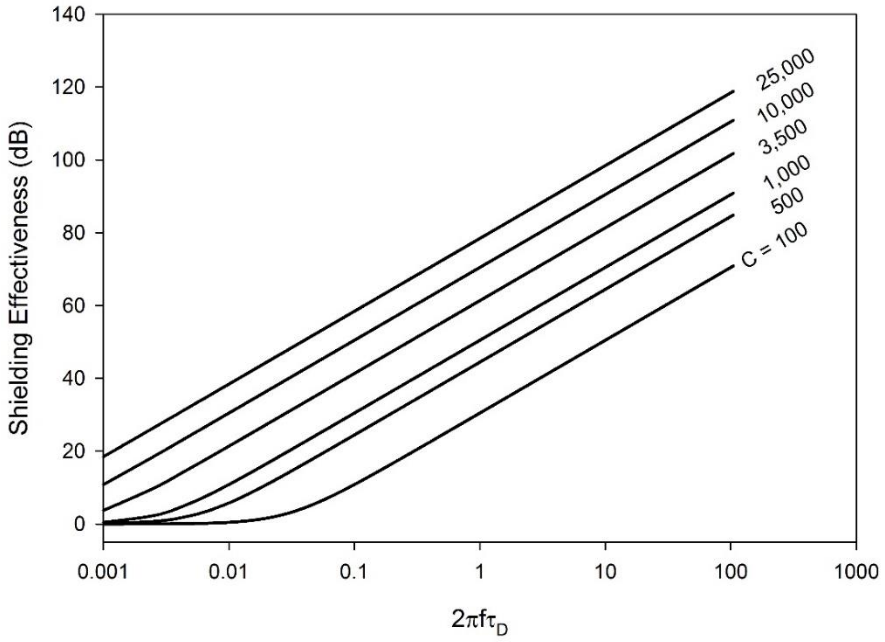
(b) Compromising

(c) Bad

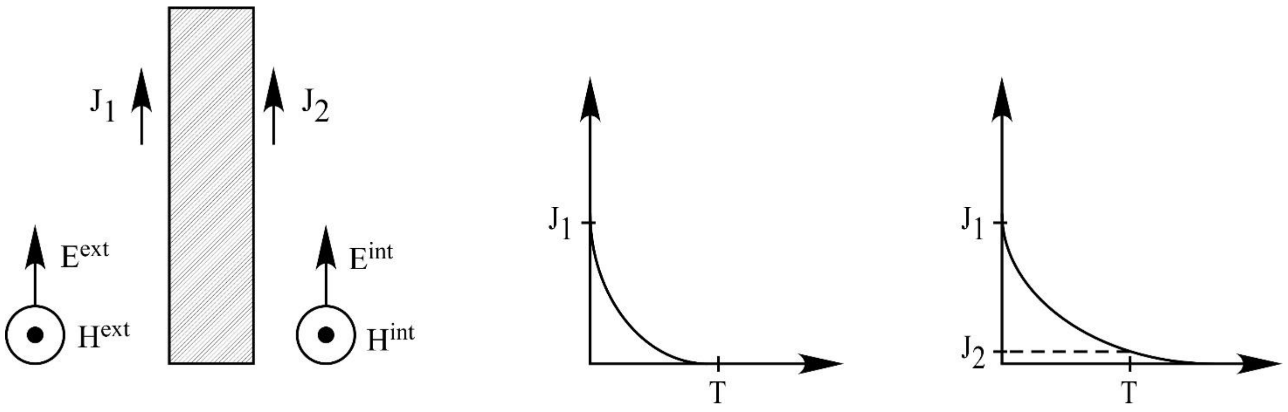


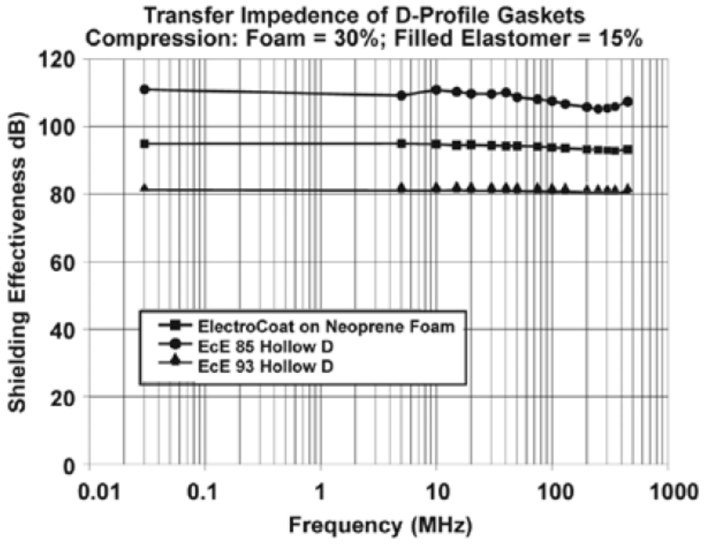

Inside module, other techniques may also be used, ground planes, multilevel circuits, EMI filters, etc.

# Enclosures




**Analyze**
**E- (capacitive)**
**&**
**H (inductive)**
**Coupling Separately**




**Amazing Commercial Products Available**

# Topology for Fault Containment within a System

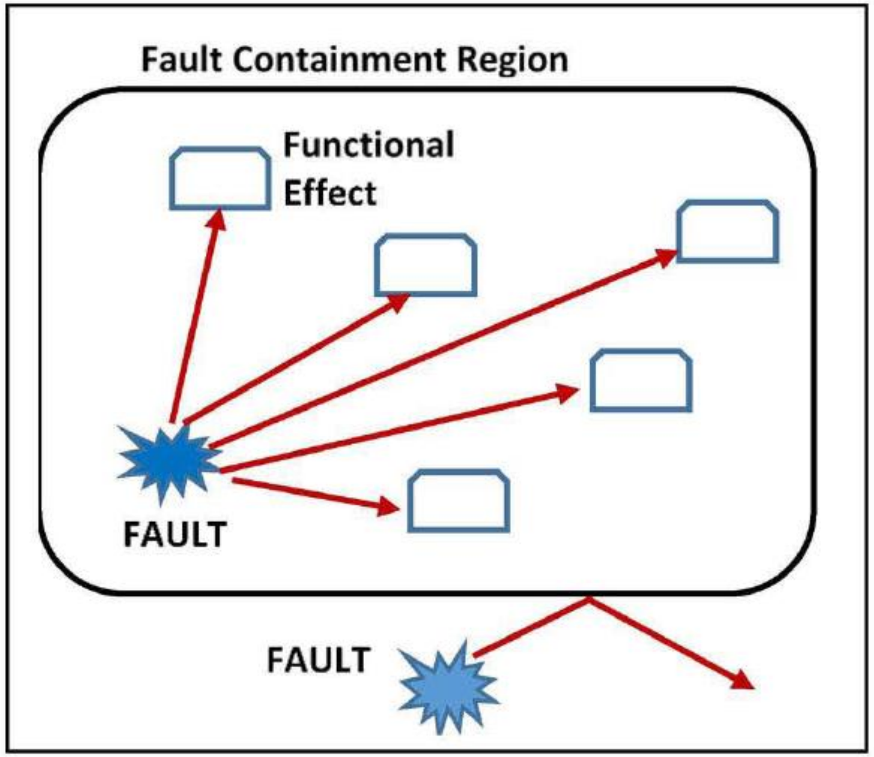



Fig. 1 Basic Concept of a FCR

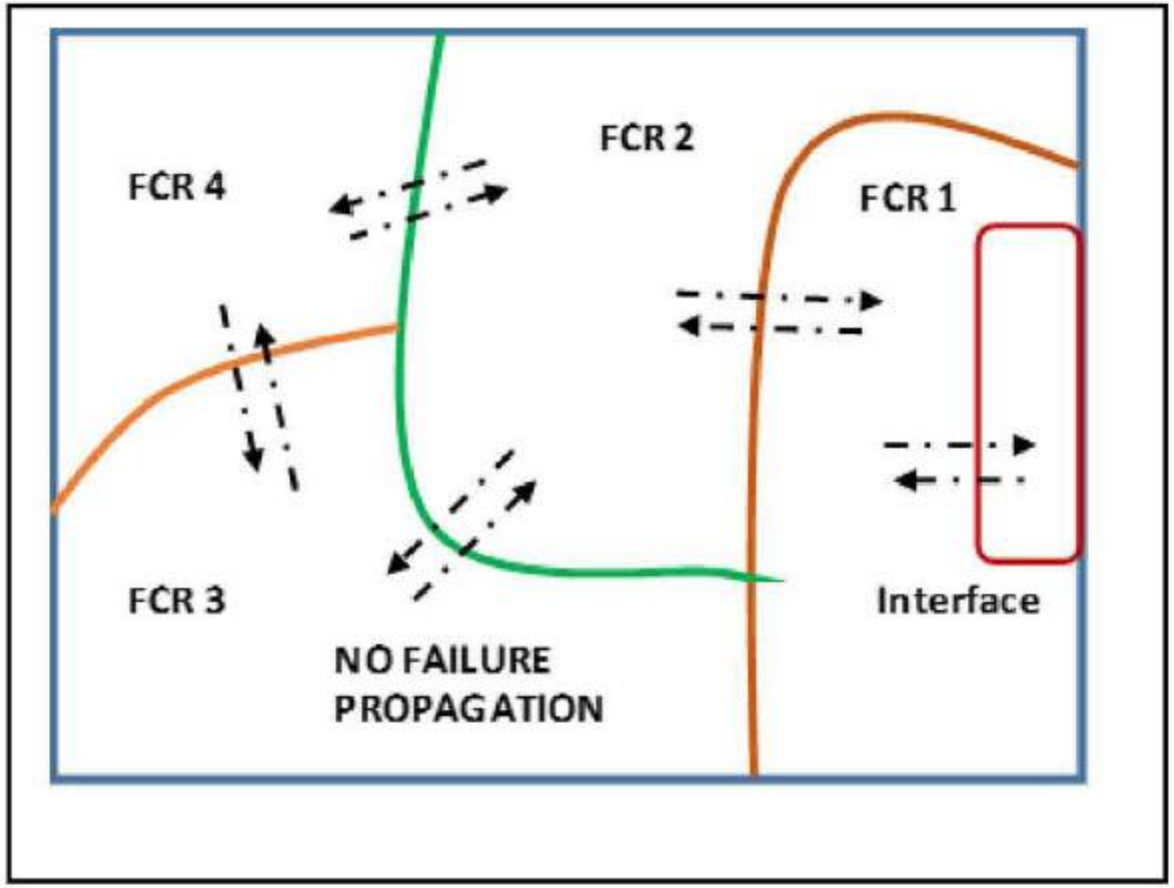
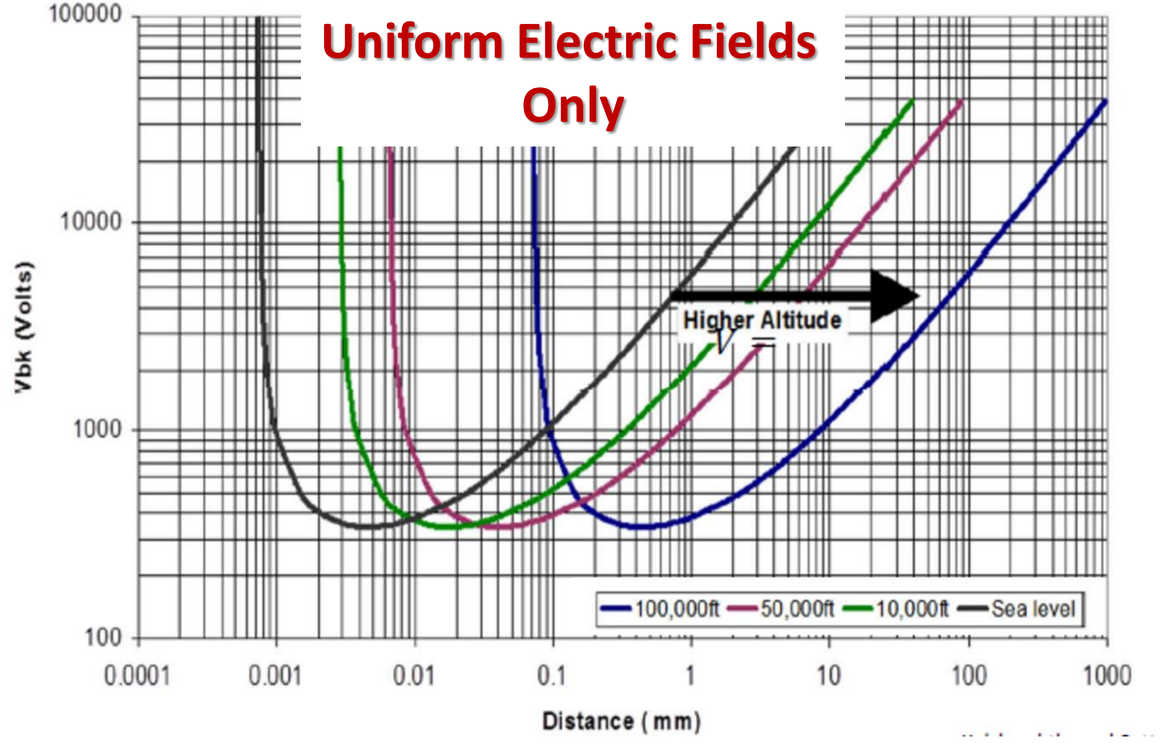
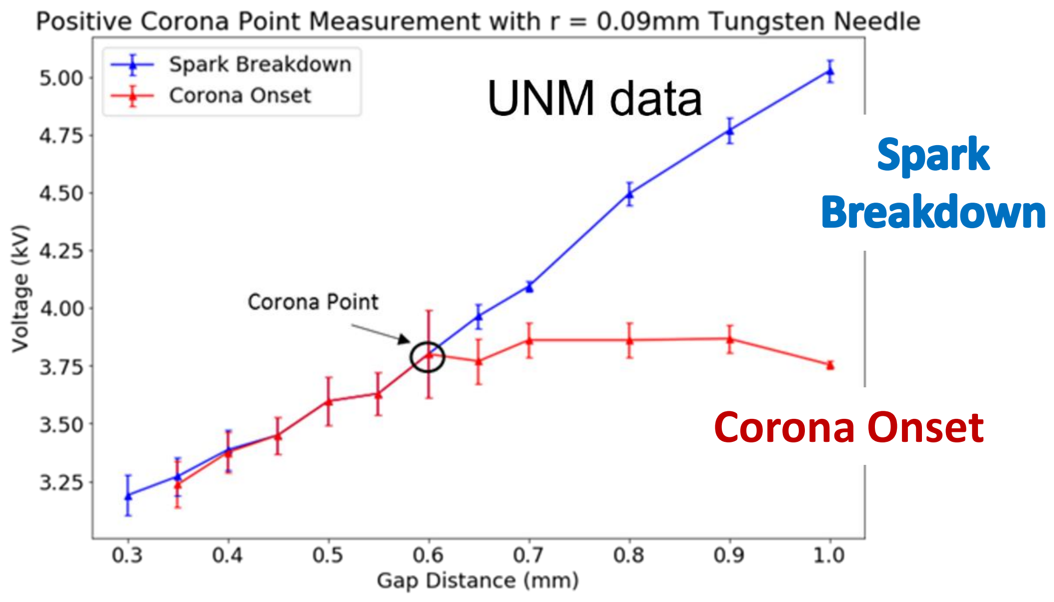



Fig. 2 FCRs not allowing failure propagation

# A Different System Consideration: The Altitude Dilemma



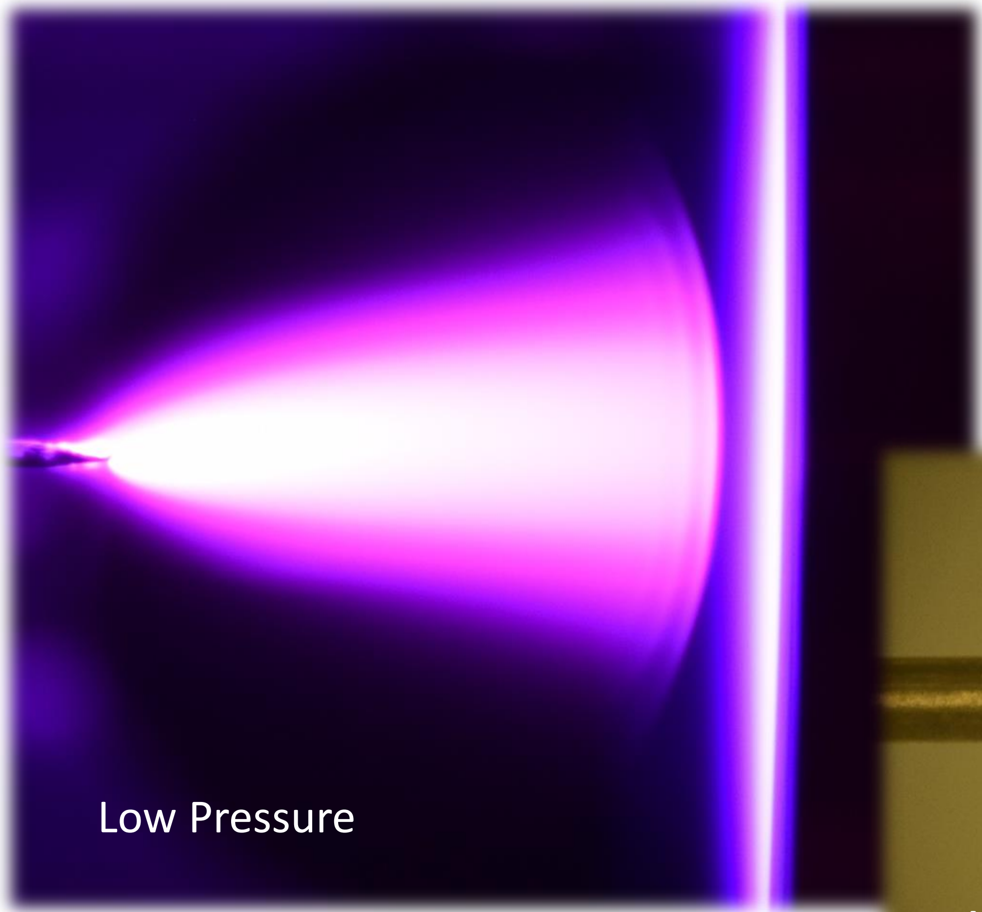

Higher altitude requires more distance for a given voltage

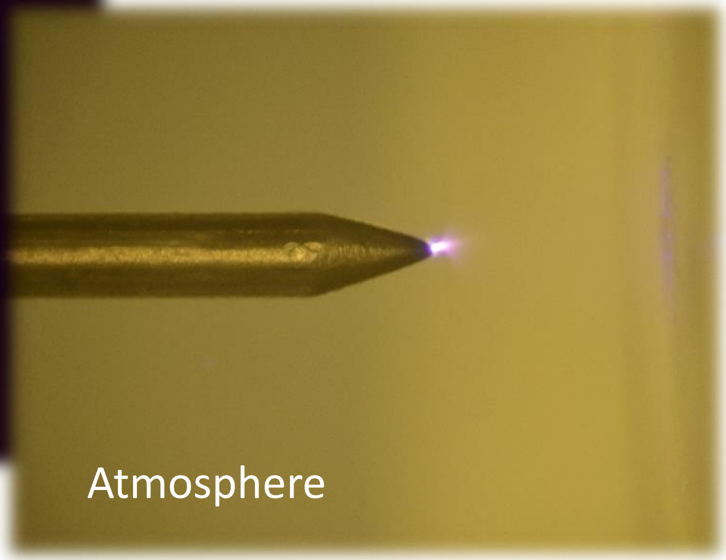



More uniformity

**In nonuniform electric fields, if only breakdown is a concern, the allowable minimum electric field distribution is much higher - several kV/cm**

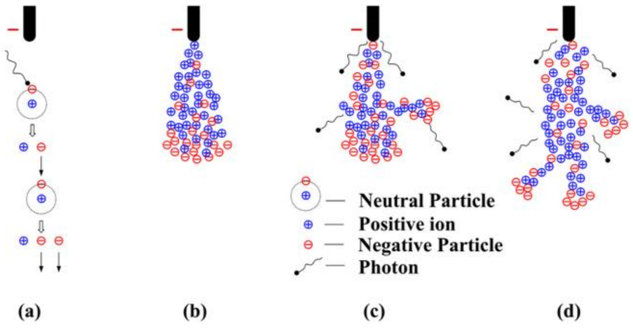
# Low Pressure DC Corona Discharge (Pin-to-Plane)



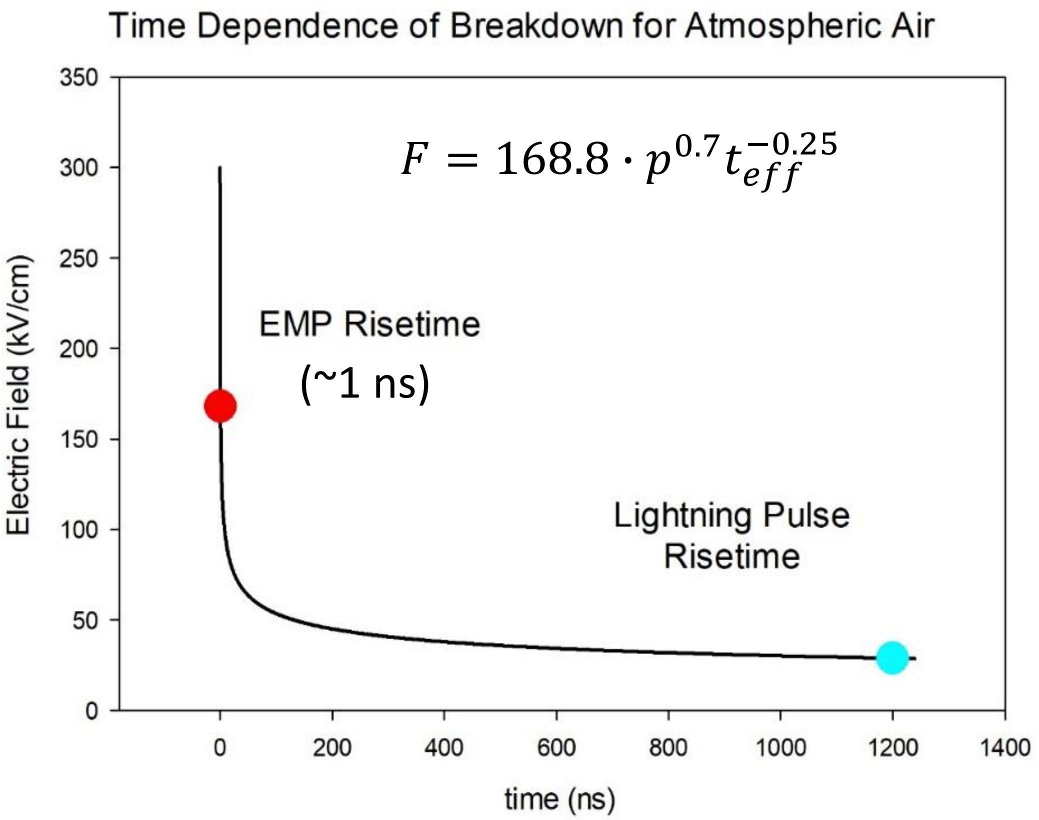



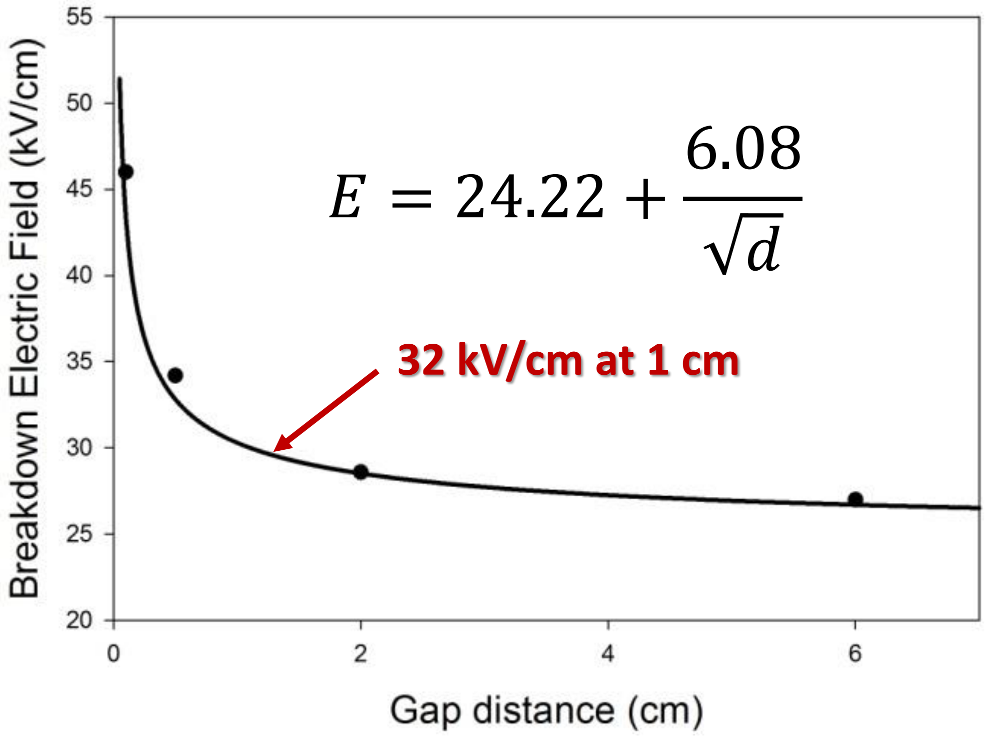

- Non-uniform Electric Field Geometries
- Stable discharge

$$R_{cor} = \frac{V}{I_{cor}}$$



# Air Breakdown




**Longer timescales & lengths allow more processes to contribute … needing less peak voltage for breakdown**


**Picasso or T. S. Eliot said ….**

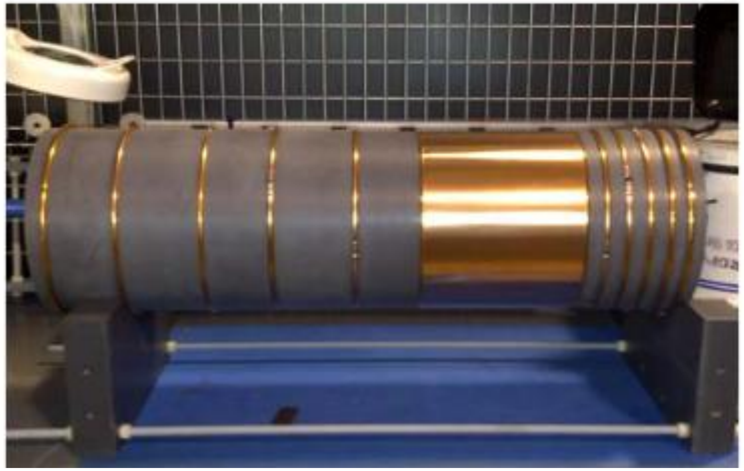
**"the good artist imitates and the great artist steals"**

**A great artist** will select elements from other's and incorporate it into their own unique mix of influences

T.S. Eliot

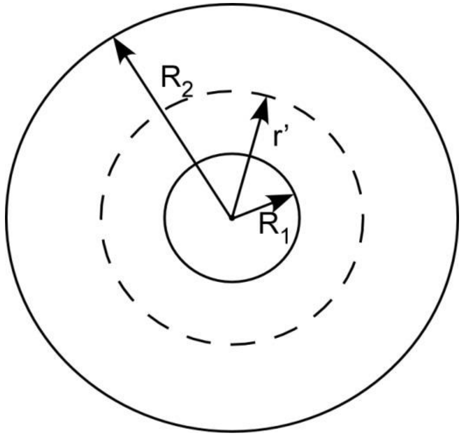
# Nesting

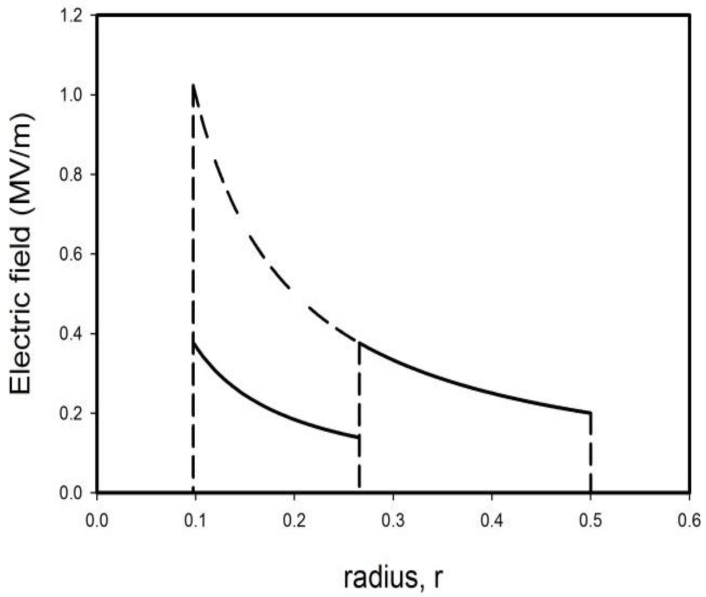
**Introduce strategically placed conductors for E field control**



Reducing PFN Marx Generator Size Using Nested Solid Insulation

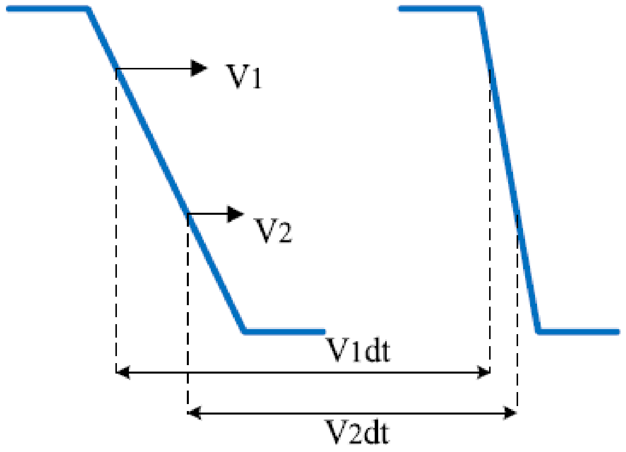
R. J. Adler, J. Gilbrech, D. New
*Applied Energetics*
*3590 E. Columbia Str.,*
*Tucson, AZ 85714*




**Determine structure – since conductors are not current carrying, how much bulk is required?**

# Ferrite Pulse Sharpeners



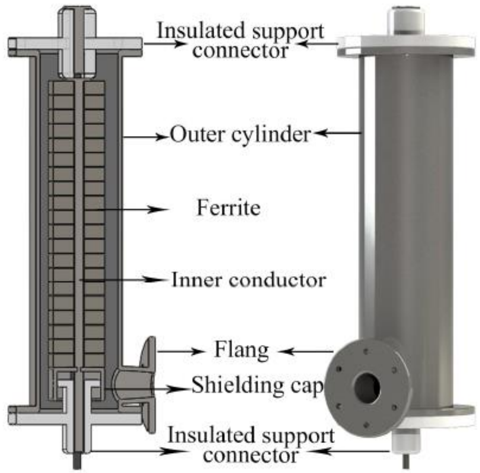




Fig. 12. Structure diagram of one-section ferrite transmission line.

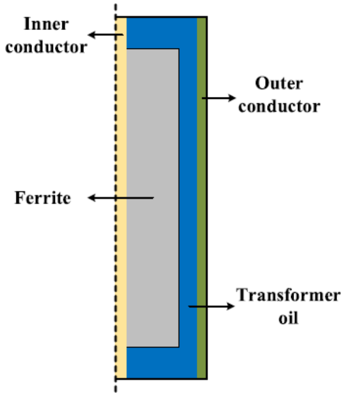



Fig. 3. Simplified 2-D axisymmetric model of the ferrite transmission line.

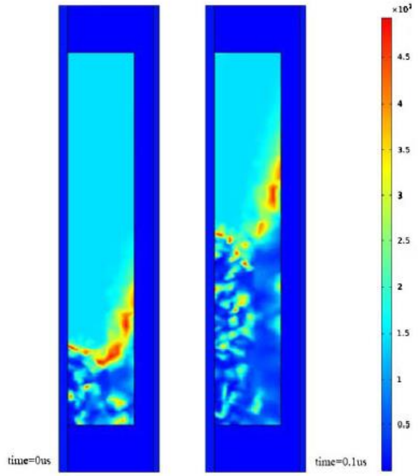



Fig. 4. Magnetization process simulation of magnetic core.

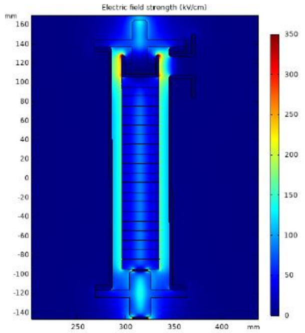
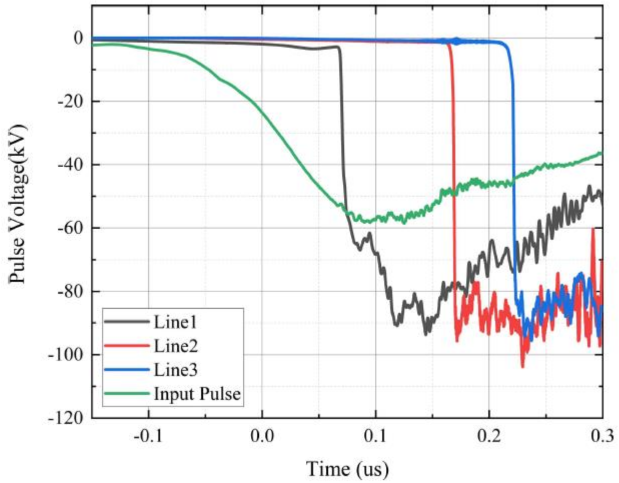



Fig. 13. Electric field simulation of a ferrite transmission line section.

IEEE TRANSACTIONS ON PLASMA SCIENCE 1

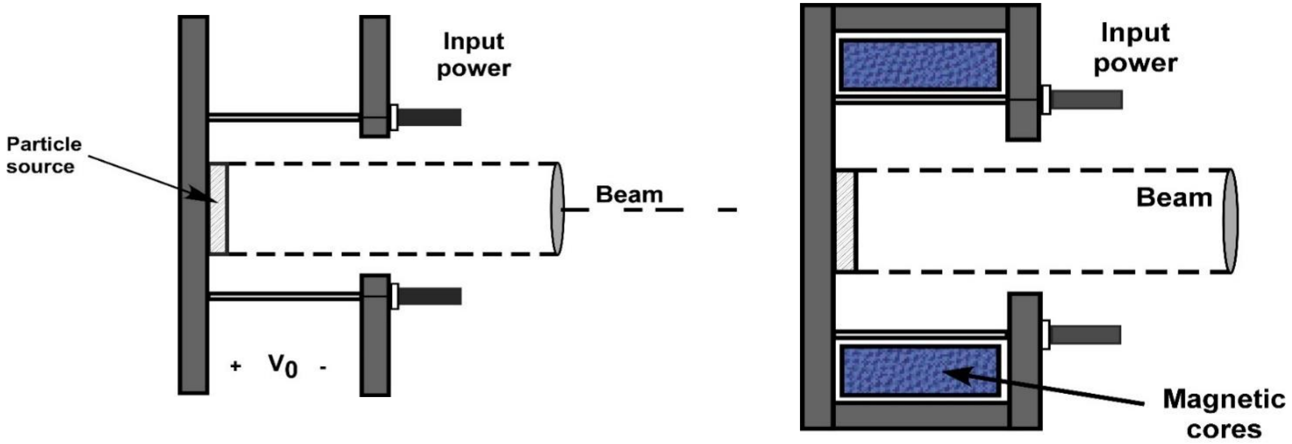
Design and Performance of a Ferrite Transmission Line Sharpener for Trigger Generator Used in FLTD

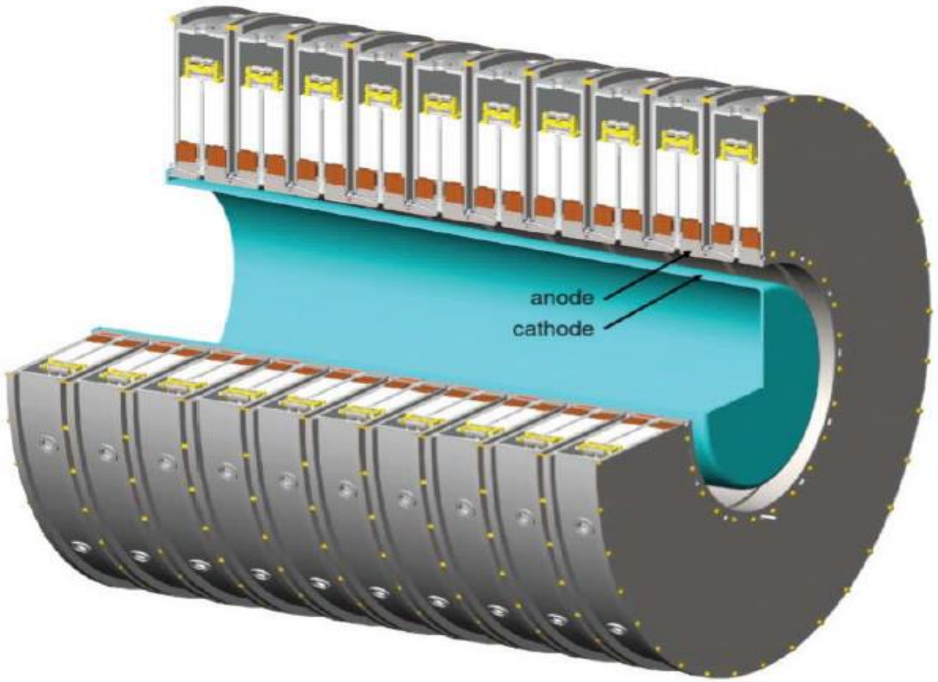
Jinbo Jiang, Zheng Luo, Yu Cao, Wanchen Cai, Jiadong Wang, and Tingqiang Cheng



# Accelerator Cavities

For accelerators and fast modular circuits


- Magnetic cores act as 1:1 transformers to deliver energy
- Cavities allow stacking
- Voltage Adder Topology demonstrated
- Needs control

# Summary

Light Triggering and Ultrafast Switches
are a key enabling technology to increase
the resilience of the evolving power system
& encourages modularity and protection